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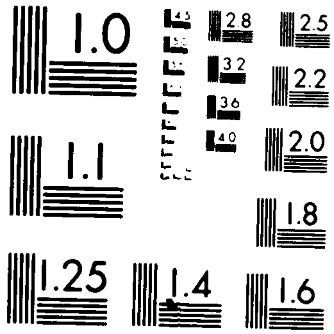

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER AFIT/CI/NR 86-81D	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) The Effects of Local Exertion and Anticipation on the Performance of a Discrete Skill		5. TYPE OF REPORT & PERIOD COVERED ~~THESIS~~/DISSERTATION 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Bruce Jaeger		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS AFIT STUDENT AT: North Carolina State Univ		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS AFIT/NR WPAFB OH 45433-6583		12. REPORT DATE 1986 13. NUMBER OF PAGES 133
14. MONITORING AGENCY NAME & ADDRESS (If different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLAS 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

APPROVED FOR PUBLIC RELEASE: IAW AFR 190-1

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The Effects of Local Exertion and Anticipation on the Performance of a Discrete Skill

by

Bruce Jaeger

Captain, USAF

1986

Pages: 133

Degree Awarded: Doctor of Philosophy (Ph.D.)

Institution: North Carolina State University

The Effects of Local Exertion and Anticipation on the Performance of a Discrete Skill

by

Bruce Jaeger

A thesis submitted to the Graduate Faculty of
North Carolina State University
in partial fulfillment of the
requirements for the Degree of
Doctor of Philosophy

Department of Psychology

Raleigh

1986

Approved By:

James Laurence Cole

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Richard G. Pearson
Chairman of Advisory Committee

ABSTRACT

A ballistic cranking task was used to study the relationship between local exertion and anticipation on performance. The move was cued by a light sequence similar to a dragstrip start. A subject could predict the move using temporal and spatial cues in the four-light sequence. The sequence was fast or slow and indicated the move would start to the left or right. Twenty percent of the time the lights switched to the opposite row during the sequence. A subject performed this skill after interpolated arm ergometry of 20%, 40%, 60%, or 80% of his arm strength.

Dependent measures were absolute error (AE) and constant error (CE) for response timing; error rate; and movement time. Results revealed Precue Speed x Stimulus Continuity interactions for AE, CE, and error rate. Switched-fast trials produced less accurate timing and more errors. Precue Speed caused subjects to respond early for slow sequences and late for fast. Exertion produced only a strong downward trend for movement time.

A major finding was that local exertion did not interact with anticipatory variables. The effects of exertion were confined to local physiological processes and did not influence cognitive functions. Additionally, there was no support for an inverted U relationship between exertion and performance. Another important result was that the switched-fast condition produced substantial performance decrements. This was attributed to difficulties the information processing system had when it attempted to modify an anticipated response.

BIBLIOGRAPHY

Schmidt, R.A. (1982). Motor control and learning: A behavioral emphasis. Champaign, IL: Human Kinetics.

BIOGRAPHY

Bruce Jaeger was born August 29, 1953 in Iowa City, Iowa to Rev. and Mrs. Robert Jaeger. He graduated from Elgin High School in Elgin Illinois magna cum laude in June 1971.

He attended the United States Air Force Academy in Colorado Springs and graduated as academic salutatorian in June 1975, at which time he was commissioned as a second lieutenant in the Air Force. Lt Jaeger graduated from the Academy with a Bachelor of Science degree in psychology. While there, he earned parachutist wings and a sailplane rating.

His first assignment was Air-Force sponsored graduate work at Purdue University. He received a Master of Science degree in psychology in December 1975, graduating with honors.

Lt Jaeger's next assignment was at the Occupational Measurement Center, Lackland AFB, Texas, where for three years he wrote and edited achievement tests for the Weighted Airman Promotion System. During this time he attended Squadron Officer School in Montgomery, Alabama, where he was a Distinguished Graduate.

He then became a flight commander at the Officer Training School, training and commissioning 92 second lieutenants while stationed there. At OTS he earned the Master Instructor rating from the Air Training Command, and in June 1979 he was promoted to the rank of captain.

Captain Jaeger's next assignment was on the faculty of the Air Force Academy, in the Behavioral Science Department. He taught introductory psychology, organizational psychology, and human factors engineering for two years, then was selected for advanced graduate work in ergonomics under the sponsorship of the Air Force.

Since August 1983 he has attended North Carolina State University, where he has been studying for his Ph.D. degree in psychology. He has recently been selected for promotion to major.

Captain Jaeger's military decorations include the Meritorious Service Medal and the Air Force Commendation Medal with one oak leaf cluster. He is married to the former Peggy Bohler of Myrtle Beach, South Carolina. He has two sons, Andrew and Aaron, and is expecting a third child in November 1986.

ACKNOWLEDGEMENTS

This is the place to thank people, so first of all, thank <u>you</u> for reading this. I have always thought thank-you's would be far more meaningful if they were stuck obtrusively into the text at those points where a thank you was merited. At least everyone would know who did what, and we'd all gain a better appreciation for the significant contributions of others.

Doing a dissertation is hard work! But it would have been downright impossible without the help and support of so many along the way. First, let it be known to all that this research was done under a grant from the Air Force Office of Scientific Research, under the supervision of the Frank J. Seiler Laboratory at the United States Air Force Academy. Further, I wish to acknowledge the equipment support under NIOSH Training Grant 5-T-15-OH-07101 (to Dr. Pearson), from which timing equipment was made available for the laboratory research. Without such aid, I would be back at square one.

My sincerest appreciation goes to the members of my committee, whose expert guidance kept me on track. To Dr. Richard Pearson, mentor and motivator, thanks for giving me The Big Picture of ergonomics. To Dr. Frank Pleasants, whose last name is truly fitting, thanks for nurturing my interest in motor skills. To Dr. Michael Joost, my idea man, thanks for opening more doors than I could possibly enter. And to Dr. James Cole, Mr. Fix-It of all that beeps, buzzes, and whirls, deep thanks for translating my equipment dreams into reality.

The supporting cast is too numerous to mention, but there are a few

stand-outs. Thank you, Rudy Salas, for your "Electronics Made Easy" course that even a simpleton could understand. I did. Thank you, Bob Troxler, for never being too busy to open up the shop and teach me how to use (safely!) another piece of machinery.

Two colleagues and friends deserve special mention. To Rick Ragan, best man and best friend, thanks for helping every step of the way. From discussing ideas to working out the bugs in the system, I'm glad you were always there. And to Susan Gray-Silva, Wizard of SAS, thank you for disclosing some of TUCC's mysterious secrets.

Oh yes, I saved the best for last. Thank you, Peggy, thank you. For listening to all the shop talk at parties. For gaining an appreciation of ergonomics despite my endless babbling about it. For making me feel good when the chips were down, and for just generally being the best thing that's happened to me.

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1. INTRODUCTION

Even in today's automated work force, many jobs still involve physical work. While it is well known that prolonged heavy activity causes eventual performance declines, the effects of more moderate levels -- particularly of local exertion -- are less known. Yet it is these more moderate levels at which the modern worker operates. What happens to skilled performance in such situations? Does a warm-up effect occur at low exertion and actually facilitate motor performance? Or do all levels of exertion cause motor functions to decline? More importantly, how may the level of physical work affect other, more central aspects of skilled performance, notably the information processing system? Indeed, little is known about how exertion may interact with other task variables to produce unique effects. This is unfortunate, since many real-world tasks must be performed in the face of some physical exertion.

Over the years researchers have uncovered a host of factors that influence skilled performance by affecting the various aspects of information processing: stimulus identification, response selection, response programming, attention, short-term memory, and long-term memory. Among these are feedback, amount of practice, task complexity, task coherency, stimulus-response compatibility, stimulus clarity and discriminability, fatigue, strategies, and anticipation (Schmidt, 1982; Welford, 1976; Wickens, 1984). Because of its critical role in the acquisition and performance of skills, anticipation is perhaps the most important of these.

Anticipation is indispensable to truly skilled activity; it is part and parcel of all skills (Fitts, 1964; Holding, 1981; Poulton, 1957; Schmidt, 1982). It enables smooth, apparently effortless, error-free performance of well-learned tasks. Indeed, there are many practical situations which rely heavily on it. Examples of jobs requiring anticipation are professional drivers, air traffic controllers, airplane pilots, process controllers, and professional athletes, though it should be noted that nearly all situations use anticipation to some degree.

Skilled performers learn to receive and process various pieces of relevant information as familiar patterns or chunks of information. Such information from the environment comes to the operator at various speeds and probabilities. The individual processes it and decides which one of several possible responses is best, then performs the action. What is observed as a seemingly smooth stream of activity is in reality a rapid series of pre-computed responses -- the intermittent ballistic servo notion developed by Craik (1948). In the short run, most situations are very predictable and actions can be anticipated, or preloaded, so that responses are linked together in an uninterrupted chain and executed at precisely the correct time. But what happens when the unexpected suddenly occurs? How does the speed at which the information has been flowing interact with unpredictability? These questions reflect the dilemma of many skilled operators. Efficient performance (rapid and accurate) demands anticipation, yet the real world is somewhat unpredictable. What are the costs and benefits of anticipation given this constraint?

Anticipation, then appears to be a prime candidate for research in conjunction with physical exertion. An investigation of the effects of exertion and anticipation on skilled performance can answer questions of practical and theoretical significance. From a practical standpoint, industrial supervisors, military commanders, sports coaches, and performers themselves want to know how various physical loads and anticipatory conditions might affect subsequent performance. From a theoretical view, specific changes in performance point to which control mechanisms are affected by such variables. Hence, the effects of physical exertion and anticipation on motor skills is a research topic of broad appeal.

Before turning to this prospect, it is helpful to review the extensive research on physical exertion and skilled performance. Although most of it has used exercise as the sole independent variable, it is nonetheless profitable to study. Examining the literature gives one an appreciation for the huge variety of topics and approaches employed to study the effects of physical work. Further, certain conclusions may be drawn from past research, although this is difficult due to the assortment of experimentation. Additionally, a critical look at the research uncovers a dismaying number of methodological weaknesses, the control of which can strengthen the present effort.

2. LITERATURE REVIEW

Because so much research has been done in this area, it is helpful to impose a classification scheme on the experiments. A workable solution is to categorize the literature by the types of skills studied. Holding (1981) presented a classification system which accounts for all the tasks to be considered. He depicted skills on a continuum in each of five dimensions:

1. Perceptual ---------- Motor
2. Open --------------- Closed
3. Simple ------------ Complex
4. Gross ---------------- Fine
5. Discrete ------- Continuous

The open--closed dimension refers to the predictability of the stimuli. A closed skill is entirely predictable (e.g., pursuit rotor tracking or bowling). In an open skill, the performer must respond to a changing environment (e.g., dual-axis tracking or driving in traffic).

Depending on the blend of these factors, a specific skill lies in one of four quadrants (see Figure 2.1). Those skills falling on the left half of the diagram rely more on exteroceptive feedback from eyes and ears, while those on the right half use primarily proprioceptive feedback. Tasks above the horizontal line may be thought of as more ballistic and preprogrammed, or at least as discrete action, with feedback coming after the response. Those below the line are more continuous in nature, i.e., corrections are made on an ongoing basis. Though Holding does not explicitly state this, the placement of a skill

on the diagram implies what demands the skill puts on information processing mechanisms (e.g., stimulus identification, response selection, response programming, use of feedback, working memory, etc.). So, for example, if a skill that is mainly perceptual in nature is disrupted by general exertion, we may infer that certain underlying mechanisms are sensitive to exertion.

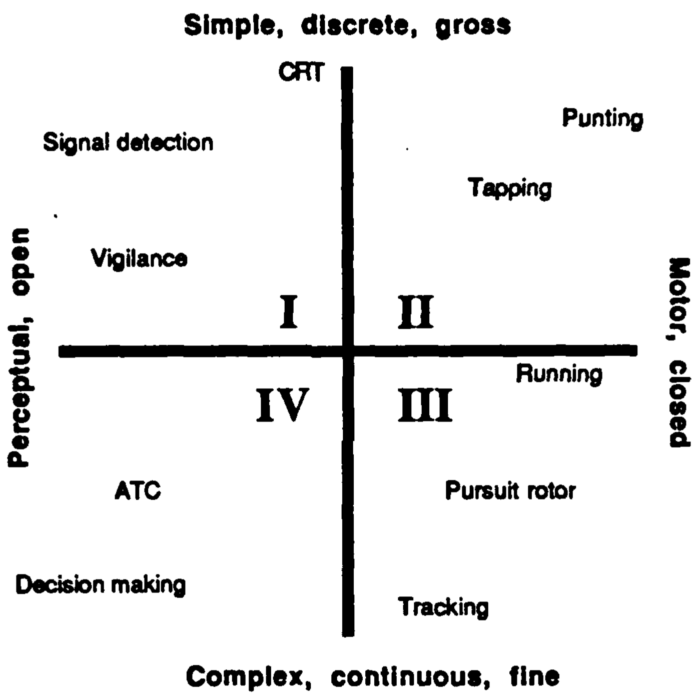

Figure 2.1. Holding's (1981) Classification of Skills.

Within this overall framework, the research is subdivided into experiments using general, or whole-body, exertion and those employing local dynamic exercise. The research in quadrant four is not reviewed here because the tasks have little relation to psychomotor skills. Those tasks are largely cognitive and involve almost no motor

components. Further, static or isometric exercise studies are not reviewed here because this form of exertion produces vastly different effects on the body: a sharp rise in blood pressure, very little change in heart rate, few calories burned, etc.

2.1 Quadrant I Skills

The types of tasks included here are those that focus on stimulus detection, recognition, and identification. In addition, they are typically simple, discrete skills.

Basic perceptual abilities have been examined by a number of researchers. Two studies were done to ascertain the effects of several levels of general exercise on line discrimination (McGlynn, Laughlin, & Bender, 1977; McGlynn, Laughlin, & Rowe, 1979). Neither experiment found any effects on accuracy, though speed of discriminations did improve. The authors suggested, however, that increased speed may only have been a practice effect. Lybrand, Andrews, & Ross (1954) used three perceptual tests, including the Müller-Lyer illusion and the Koh Block Designs. They found that mild general exercise improved what they termed "perceptual organization."

Moving to somewhat more applied work, Bard & Fleury (1979) used a visual search task and a related skill, a visual field task. Despite heavy ergometer work prior to testing, there were no effects on skilled performance. Fleury, Bard, Jobin, & Carriére (1981) conducted a follow-on experiment using three types of treadmill exercise: a short, intense, alactacid effort; a bit longer, heavy, anaerobic (lactacid) effort; and an aerobic effort. None of the exercise types affected

performance on the visual detection task.

Similar to target recognition tasks, save for drops in stimulus frequency and predictability, are vigilance tasks. Schmidtke (1976) used a Mackworth clock task and found ergometer work at 75 percent aerobic capacity produced an immediate and sustained performance decrement as compared to rested subjects. A more moderate exercise level of 50 percent aerobic capacity produced an eventual performance drop that was significantly below rested subjects, though at first the subjects in this condition did slightly better than others. Bonnet (1980) tested auditory vigilance after a demanding treadmill walk of 20 miles that took 6.5 hours and consumed approximately 5000 calories. He also found vigilance performance declined after the treatment, though he acknowledged that the decrement could have occurred after any prolonged work period.

As a brief summary, one study using mild exertion reported improved perceptual abilities while two experiments on vigilance, both employing fairly heavy exertion, demonstrated performance decrements. Four other studies, three of them using multiple workloads, found no effects from exertion. The results of these studies do not support any general conclusions on the relation between exertion and quadrant I skills.

Reaction Time Tasks. Reaction time tasks still involve a large amount of perceptual processing, but they also contain some cognitive, response-selection activities. This is especially so for choice reaction paradigms, where the response must be selected after the stimulus appears.

Simple Reaction Time (RT). In several experiments that employed bench stepping (a whole-body exercise), RT was found to be unaffected (Elbel, 1940; Meyers, Zimmerli, Farr, & Baschnagel, 1969; Phillips, 1963). This held for reaction times tested at various sites: finger, hand, and foot. Local exercise has produced mixed results. Phillips (1963) again reported no effects. Sheerer & Burger (1972) observed a slight slowing (10 msec) of reaction time across several exercise levels. But Roca (1980) saw better times after he gave subjects what he termed specific "warm-up" exercises, and Babin (1966) also found that RT improved following light exercise, though it became slower with heavy local work. He suggested reaction time might follow an inverted U curve as a function of exercise intensity.

Fractionated Reaction Time. With advances in electromyography, new types of RT experiments have been developed. EMG readings can be used to discern two major components of reaction time, premotor and motor time. The former is thought to reflect demands on central processing while the latter may be attributed to separate processes that transmit muscle firing instructions and ready the muscle(s) for the response. Note that premotor and motor time occur <u>before</u> any overt movement; they are both part of reaction time.

Only Kroll (1973; 1974) has used fractionated reaction time in dynamic exercise experiments. Neither study found significant effects on reaction time or its components, though his earlier experiment noted a small change in the relative sizes of premotor and motor time within total reaction time. While both studies involved fairly mild exercise, the earlier one did use a somewhat higher level.

Choice Reaction Time (CRT). As mentioned above, while RT tasks retain emphasis on perception (detection and identification of stimuli), they also rely more on cognitive, response selection processes. This is especially true for CRT tasks. According to Holding (1981) these skills lie midway between quadrants I and II, representing an equal weighting of resources (refer to Figure 2.1).

Most investigators have reported CRT does not change from whole-body exercise (Bonnet, 1980; Dechovitz, Schutz, & Sadosky, 1974; Higgins, Mertens, McKenzie, Funkhouser, White, & Milburn, 1982). A recent study concluded the same for local exercise (Williams, Pottinger, & Shapcott, 1985). The Dechovitz et al. (1974) and Williams et al. (1985) experiments used multiple exertion levels. One well-controlled experiment runs counter to the above findings. Levitt & Gutin (1971) employed four levels of treadmill work and collected choice reaction time data concurrently with exercise to avoid any recovery by subjects. They found the classic inverted U function; moderate exercise improved choice reaction time while light or heavy resulted in worse times.

Conclusions from the reaction time literature are tentative at best. It appears that whole-body exertion has little effect on simple or choice reaction time -- only Levitt & Gutin (1971) reported significant results. Data from local exertion studies are only a bit more promising. Effects seem likely, but they are far from consistent. This may be due in part to the relationship between the specific muscles exercised and those used for the task, for example, the motor time component of fractionated reaction time might be variably affected.

It is tempting to recommend more research here, especially using the

technique of fractionated reaction time in a local exercise paradigm. However, some feel that preoccupation with pure reaction time tasks is a mistake (Schmidt, 1982; Turvey, 1977). The tasks seem highly artificial and do not relate well to real world skills. Recent experiments using measures of reaction time and subsequent performance on practical skills that supposedly employ all the processing steps that reaction time reflects have shown no relationship between the two (Nielson & McGown, 1985; Siegel, 1985). In other words, laboratory RT measures did not predict performance on practical skills that required fast, efficient information processing.

Timing Tasks. A more practical version of the reaction time paradigm is the coincidence-anticipation task. This laboratory task recognizes the importance of temporal anticipation -- the internal timing of stimulus events and their corresponding responses. The approach acknowledges that humans are rarely confronted with sudden, unexpected stimuli nor do people typically respond in a "knee-jerk" fashion to environmental cues. Rather, with learning, individuals are able to predict what will happen next and time their responses to meet the anticipated stimuli. Common examples are catching a ball, stepping onto an escalator, and stopping a car when a traffic light turns amber. In a highly learned skill, the response coincides with the stimulus so the apparent RT is zero. In truth what is happening is the reaction time has been moved forward in time -- perhaps based entirely on a precue as the effective stimulus -- so that the psychological refractory period is over by the time the primary stimulus occurs.

Four experiments in the exertion area have been conducted using a coincident timing task. Wrisberg & Herbert (1976) used well-trained subjects and extremely heavy exertion levels: 90% of aerobic capacity or a 90% decrement in local muscle strength. They found that general exertion produced premature responses while local exertion produced late ones. However, this occurred for the FIRST post-exertion trial only, a surprisingly transient effect. They also found for the first five trials after exercise that the variability in timing was higher for both groups compared to the control. These effects are interesting, but given the high level of physical work they seem small indeed. Two other studies also had little success in disrupting temporal anticipation. Though they used very high levels of general exercise, neither Bard & Fleury (1978) nor Fleury, Bard, & Carrière (1981) found any effects on timing.

More recently Howard, Shea, & Herbert (1982) investigated the role of feedback in a coincident timing task. Subjects exercised the same muscles used in making the timed response. The task involved leaving point A as the sweep hand on a 1-sec clock reached the top, then moving to point B as the clock hand passed a mark at the bottom. They found that heavily fatigued subjects were less able to process feedback during a move, i.e., if subjects began a move early they finished it early and vice versa. The researchers concluded that fresh subjects can use closed-loop control to modify an ongoing movement. On the other hand, physically fatigued subjects are less able to feed back the existing cues and respond instead in a ballistic, programmed fashion that is unaltered even when subjects perceived timing errors during the move.

2.2 Quadrant II Skills

Skills in this section are somewhat more motor-oriented. As in quadrant I, they are fairly ballistic in nature: quick, programmed movements that can be classified as discrete trials. Many have speed as their primary criterion.

Inconsistency looms large for the results of these experiments. Using intense general exercise via stool stepping, Phillips (1963) found that ballistic arm cranking movements increased in speed. But Welch (1969) also used stool stepping and the same cranking task and found no effects from exercise. The Levitt & Gutin (1971) experiment mentioned above also studied movement time, which became better as exercise intensity increased. From this experiment and other work, Gutin (1973) proposed the Exercise-Induced Activation (EIA) hypothesis. Based on arousal concepts (cf. Duffy, 1962; Malmo, 1955), it predicts an inverted U relationship between arousal that has been induced by exercise and performance on perceptual-motor skills (see Figure 2.2). Very simple, speeded tasks (such as in his 1971 study) continue to benefit from higher and higher levels of arousal, as long as the particular limb segments involved in the move are not becoming physically fatigued. Tasks requiring more cognitive abilities or that are more difficult (such as those using fine control, decision-making, or the processing of many cues) peak at more moderate levels of exertion. According to Gutin, these relationships are best observed when the muscles involved in skill execution are not overtaxed.

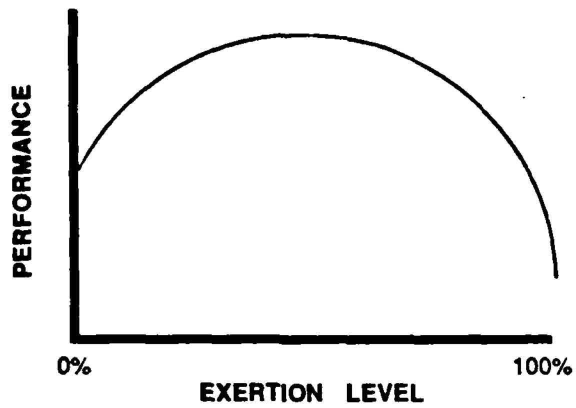

Figure 2.2. Exercise-Induced Activation and Its Effects on Performance.

An experiment by Dickinson, Medhurst, & Whittingham (1979) using arm exercise partially supported Gutin's EIA idea for performance on Fitts' tapping task. Performance with the preferred arm peaked at 20% of a person's maximum exercise capability, then it declined with higher levels of exercise. However, they explained the experimental findings another way, i.e., Richards' (1968) two-factor theory. This theory states that there is a metabolic warm-up effect for muscles, as well as a physiologic fatigue effect. At lower levels of exertion, the first factor is dominant and performance is facilitated, while at higher levels muscular impairment occurs and performance declines. This theory, like the EIA hypothesis, predicts an inverted U relationship between exercise and related motor skills. More will be said about these theories in the section on warm-up.

There are many other experiments which do not support an inverted U function. Studies on general exercise (Bonnet, 1980) or local exercise (Barnett, Ross, Schmidt, & Todd, 1974) reported that movement times were

simply slower after exertion. Still others reported no effects on arm movement speed after general work (Welch, 1969) or local work (Phillips, 1963; Williams et al., 1985). In sum, there is no overwhelming evidence from the quadrant II skills to support EIA theory or the two-factor theory.

At this point certain statements can be made concerning the effects of exertion on ballistic motor skills. General exertion seems to have produced few, if any, reliable effects. Local exertion at low to moderate levels may aid performance; research on warming up can add to the knowledge in this area (see the discussion on warm-up). With heavier local exercise there is likely to be a performance decrement on speeded skills. This, of course, implies an inverted U relationship, though such conclusions have not been supported by experiments that used a broad range -- multiple levels -- of exertion.

2.3 Quadrant III Skills

Skills in this quadrant have motor components which require finer control, continuous control, or more elaborate patterns of movement than the ballistic tasks just discussed. Examples include tracking, balancing, and running.

Running is often considered a fairly ballistic, programmed task. Yet it also employs continuous control, proprioceptive feedback, and precise muscle sequencing d timing. As such it falls midway between quadrants I and II (refer to Figure 2.1). Various research teams have examined the running cycle using high-speed cinematography to freeze action and computer equipment to digitize the spatio-temporal patterns

of the progressive phases of the running stride. Findings are in harmony; as runners become physically fatigued their gait patterns become irregular (Bates, Osternig, & James, 1977; Elliot & Ackland, 1981; Sprague & Mann, 1983). Specifically, there is irregularity of timing and force production, plus less efficient spatial patterning. Such results hearken to Bartlett's (1943; 1953) observations on fatigue, namely, it disrupts internal timing mechanisms and causes changes in the patterning of responses. It is important to note that all three running studies examined conditions that produced severe whole-body *AND* specific muscle exercise simultaneously. Therefore, it is unclear whether the breakdown in skill was due to central or local factors, or both.

A skill that requires continuous control, frequent use of feedback, and finer motor responses is tracking. The effects of exertion on tracking performance, even when the specific local muscles have been worked, appear to be relatively minor. Hammerton & Tickner (1968) used stool stepping of moderate intensity and found no effects on a first-order tracking task. However, on a more difficult, second-order tracking task they did see a decrement in performance but it was only for subjects who were most affected by the exercise, i.e., those less fit. In essence, the task had to be difficult and the physical work severe before any effects were manifested. Using local exercise and a tracking task that relied on thumb control, Hammerton & Tickner (1969) found a brief decrement in tracking when the thumb itself had been exercised but not when the whole hand had been worked. The decrement lasted about one minute. Benton & Bateman (1980) administered local

exercise to the nonpreferred arm and looked for a tracking decrement in the preferred arm. They saw a transient effect that lasted for 10 seconds. Finally, Higgins et al. (1982) found whole-body exercise produced no effects on tracking. Taken together, it appears that both forms of exertion may disrupt tracking but the effects pass quickly. Further, it typically takes a high level of work to produce any changes in performance.

Steadiness tasks epitomize fine, continuous-control skills. Gutin, Fogle, Meyer, & Jaeger (1974) investigated the effects of several levels of general exercise on stylus steadiness. As they predicted, steadiness declined for all exercise conditions, with the worst performance occurring after the highest exertion. Kao, Wang, & Chiu (1978) employed a different exercise paradigm with a steadiness task. Rather than manipulating the work intensity, they changed the muscle groups that were exercised: whole-body, arm, hand and fingers, and fingers only. They found that as the exercise involved muscles closer to those needed in the task, there was more and more interference (worse performance). Such results suggest a specificity principle for exercise and provide insight as to why so many general exercise studies demonstrate no effects on skills using the hands or arms. It also reinforces the notion that local exertion affects certain local motor control mechanisms.

A practical application of steadiness is pistol shooting. Evans (1966) examined the effects of four levels of treadmill exercise on the speed and accuracy of pistol firing. Evans found no effects for accuracy, but speed of firing did decline. However, these results (like

so many in the exertion field) were clouded by practice effects, recovery, and nonstandard workloads for subjects.

One last study on precise control dealt with the fine manipulative requirements of the Purdue pegboard. Davies & Ward (1978) observed no effects from moderate to heavy ergometer work. Local arm exercise, however, produced immediate and rather persistent decrements in performance. Subjects performed significantly worse at 0 and 5 minutes after exercise, though by 30 minutes they had returned to normal. These results agree with Kao et al. (1978) on the specificity effects of physical effort.

To summarize, there is likely to be an effect from exertion when the subsequent skill relies on those muscles that have been previously exercised. For tasks requiring very fine control and continuous peripheral feedback, local or general exertion is apt to hinder performance. However, certain skills in this quadrant seem surprisingly immune to physical loads -- tracking tasks are a good example.

2.4 Warm-up

A particular line of research dealing with warm-up effects has been set aside for a number of reasons. Done mostly in the late 1950's these experiments investigated the potential benefits of various warm-up activities. Thus, the purpose of these investigations is clearly different from other exertion literature. The research cited in the previous sections looked for <u>any</u> effects -- positive or negative -- on basic and applied skills. On the other hand, warm-up research has

sought to determine what preliminary activities might aid performance. It was (and is) widely felt that warming up before an athletic event improves performance. Research designed to test this idea was fairly narrow in scope and introduced a number of additional distinctions from other exertion literature. As implied above, the tasks under observation were often sports-oriented (e.g., bowling, swimming, throwing). Then, too, the exercise levels used in such experiments stemmed directly from the phrase "warm-up"; most studies only used light exercise as the treatment.

Turning first to the nonsignificant findings, Karpovich & Hale (1956) reported that warm-up related to the follow-on skill (either sprinting or cycling) had no effects. Similarly, Matthews & Snyder (1959) saw no effects from specific warm-up activities on subsequent sprint running. Massey, Johnson, & Kramer (1961) concurred with these results; warm-up had no effect on speed of pedalling. Finally, Skubic & Hodgkins (1959) investigated the idea of specificity by administering related and nonrelated warm-up activities. They reported no effects on cycling speed, softball distance throws, or basketball tosses.

Other researchers have reported beneficial effects of warm-up activity. Thompson (1958) investigated the effects of both task-specific and general warm-up on a number of practical skills. He found specific warm-up improved speed and endurance in swimming, accuracy in basketball foul shooting, and accuracy in bowling. There were no effects for typing speed or accuracy. Several other researchers have also found that the most beneficial type of warm-up is an activity that is related to the upcoming skill (DeVries, 1959; Kaufmann & Ware, 1977;

McGavin, 1968; Pacheco, 1957; Roca, 1980; Swegan & Yankowski, 1959). An observational study by Singer & Beaver (1969) reported that bowling scores improved frame by frame and game by game. However, these data are hopelessly confounded by practice effects. Only two studies found benefits from nonspecific warm-up. Michael, Skubic, & Rochelle (1957) found general warm-up improved the distance of softball throws, while McGavin (1968) reported whole-body exercise increased the speed of leg movements. The latter study employed general exercise with leg muscles, so the conclusions may be more appropriate for specific warm-up.

Only two warm-up experiments systematically varied exercise intensity across multiple levels. Richards (1968) employed one, two, four, and six minutes of stool stepping as a precursor to a jumping task. The data suggested to her a two-factor theory of motor performance, as mentioned earlier. One, there is a metabolic warm-up effect for muscles which improves subsequent performance. This factor includes increased blood flow to the muscles, which enhances energy supplies and speeds waste removal, plus higher muscle temperatures for more efficient fuel burning. It is prominent at lighter levels of exercise. Two, there is a physical fatigue effect which causes decrements in performance. The rapid build-up of lactic acid and oxygen shortages are two aspects of this factor, which dominates at higher levels of exercise. Note that, at least for discrete, ballistic skills this theory can predict an inverted U relationship between exercise intensity and performance. It is a simpler explanation than Gutin's Exercise-Induced Activation hypothesis, for it relies chiefly on local

events. As such, it seems a more desirable approach. Unfortunately, it cannot deal with perceptual skills or fine control skills, and it lacks explanatory power for the case of general, nonspecific exertion. It does, however, suggest that there should be no effects on central information processing.

Though titled a warm-up study, Bonner's (1974) experiment more closely resembles conventional exertion research. In this well-controlled experiment Bonner administered five levels of ergometer exercise to subjects, then examined the effects of this work on cycling endurance at a heavy load. The lowest three preliminary exercise bouts aided follow-on performance, the next one had no effects, and the highest warm-up intensity produced strongly negative effects on cycling endurance. The results are in concert with other data on specific warm-up. Moreover, they lend strong support to the two-factor theory of Richards.

Unfortunately, practice effects, muscle recovery, and nonstandard exercise doses plague the warm-up research. Further, researchers in this area often failed to precisely define what the exercise was or establish performance criteria for the sport under investigation. There is yet another significant confound that deserves attention, one that applies particularly to specific warm-up. The confound has to do with the concept of activity sets (Nacson & Schmidt, 1971) and deserves some special consideration.

For many years it has been known that when a person returns to a skill after a period of time away from it, initial performance shows a decrement. As a person continues in the skill, the early poor

performance soon vanishes and the individual's peak ability becomes apparent. Experiments were conducted to see how this "warm-up decrement" could be mitigated, and also to try to identify the cause of the phenomenon. The most promising line of research dealt with the idea of activity sets. Among other things, an activity set is supposed to involve mental preparation for the upcoming responses (i.e., selecting and coding the muscle firing patterns), an appropriate level of arousal for the activity, and specific muscular effects (an increased readiness to respond via a number of physiological mechanisms).

When a performer has been away from a skill for a time, his activity set is lost, causing the temporary warm-up decrement. When the skill is resumed, the set is quickly re-established and the decrement is soon eliminated. Experimentation supports this explanation. Practice tasks that were either psychologically related (by timing and/or patterning) or physically related to a criterion skill all but eliminated warm-up decrement (Nacson & Schmidt, 1971; Schmidt & Wrisberg, 1971). As an example of psychological relation, practice activities that mimicked response patterns but used the nonpreferred limb eliminated warm-up decrement in the subsequent skill performed by the preferred limb. Activities that involved unrelated but physically effortful responses with either limb did nothing to change warm-up decrement. Hence, there was no purely metabolic warm-up effect.

The point of the discussion is this: Warm-up experiments are confounded because improved performance could be due solely to activity sets. How much of the purported benefits from warm-up can be attributed

to only preliminary muscular exertion remains indeterminate. Some assert there is absolutely no facilitation from the mere physical work and that the benefits of warm-up come only from psychological expectations that warming up will help performance (McArdle, Katch, & Katch, 1981).

2.5 Summary of Literature Review

Though the research has been substantial, unequivocal statements about the effects of exertion on performance are hard to make. This is so for a number of reasons. First, the huge variety of studies has made it difficult to unify the research results. As is evident, there are many ways to manipulate the exertion variable (e.g., whole-body, local dynamic, local isometric; plus numerous intensity levels, durations, etc.). There are even more dependent measures with which one can assess effects. Indeed, because researchers have taken full advantage of this variety, no consistent line of study has emerged. As a result, the field has remained in relative disarray, with few standard procedures and even fewer standard results (Hayes, 1976).

Another problem that besets the exertion research is that of experimental control. In particular, a large proportion of the studies failed to account for individual differences in physical capacity. For example, a nonathletic bookworm and a strapping farm boy may have been assigned to the same group and given the same physical workload. It is clear that they would not experience the same reactions to a given amount of work. In such experimental designs conclusions about the effects of exertion are untenable since subjects within a group do not

react uniformly to the treatment (see Figure 2.3a). While this appears to be an obvious control problem, only 11 of the 75 experiments cited above accounted for individual capacity by assigning the same relative exertion to subjects within a condition, i.e., a percentage of each individual's maximum capacity (see Figure 2.3b).

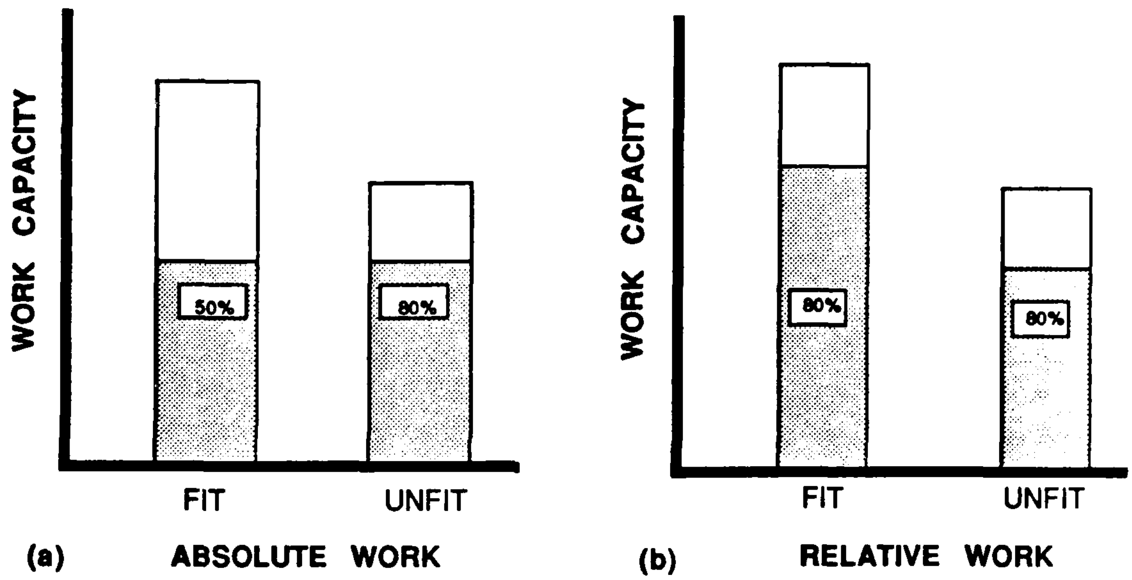

Figure 2.3. Absolute vs. Relative Work.

A related confound is recovery. The pure effects of exertion cannot be observed if individuals are allowed to recuperate before or during performance of the criterion task. When recovering, the subject actually experiences a variable load, beginning with the maximum induced by the exercise bout to a minimal, resting level. The influence of exertion is, therefore, changing over time in an unpredictable manner and there are no uniform effects (refer to Figure 2.4a). The problem can only be solved by administering exercise concurrently with the

criterion skill (which is logistically quite difficult) or by interpolating exercise between short blocks of trials (see Figure 2.4b).

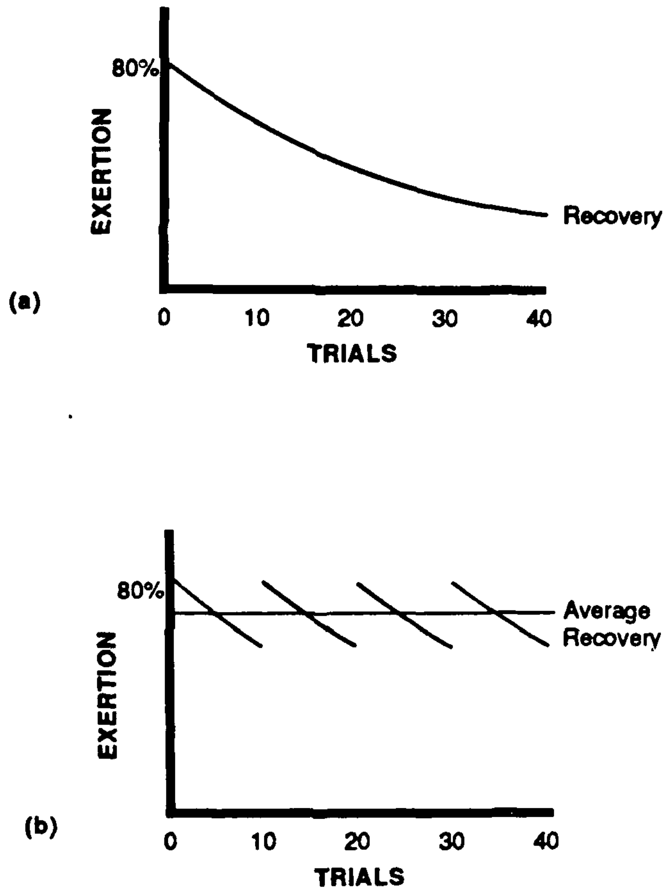

Figure 2.4. Recovery vs. Interpolated Exercise Bouts.

A third pervasive weakness of much experimentation concerns the suspected relationship between exertion and skilled tasks. As stated above, many think this relationship takes the form of an inverted U. But such a relationship between exertion and performance has been directly tested in only a few experiments. To see if the data fit such

a quadratic function, one must conduct an experiment that uses multiple levels of exertion. Unfortunately, only 14 of the 75 studies have done so. [Note: These do not necessarily coincide with the 11 experiments that employed relative exertion.]

What, then, is known about the effects of physical exertion on information processing, motor control mechanisms, and the performance of skills? Unfortunately, much less than the copious amounts of research would imply. While not explicitly rejecting any data as unusable, nevertheless a large portion of it lacks explanatory power because of the methodological weaknesses discussed above. Keeping this in mind, what follows are a few conclusions from the literature.

1. Exertion is more apt to affect local subsystems than central mechanisms of control. Effects on central motor control processes (e.g., coincident timing, response selection) are possible, but much less certain. Central effects may be observed when exertion is heavy and there are severe systemic reactions. In this case the effects on performance will probably be negative.

2. When using reaction time to reflect central effects, exertion produces unpredictable results. This is probably due to the variety of RT paradigms used, the type and severity of exertion, and variable effects on the motor time component of fractionated reaction time.

3. There are too few multiple exertion studies -- and even less using a standardized exercise dose -- to accept Gutin's Exercise-Induced Activation hypothesis or Richards' two-factor theory. Further, since the literature reported that many effects were unique to the task, the

ultimate success of either theory appears in doubt.

4. There appears to be a specificity principle for exertion and skilled performance. The closer the exercised muscles are to those needed in the skill, the more effects (positive or negative) are likely.

5. Fine control tasks are more susceptible to the detrimental effects of exertion, especially when exercise is of the muscles needed for the task.

6. Heavy exercise of local muscles causes declines in speed or force produced. In some cases (such as running) the exercise may lead to a breakdown in the timing and spatial patterning of reponses. It is unclear if these are local or central effects.

7. Heavy exertion is the most likely to manifest effects on performance, these generally being negative.

8. Light to moderate physical activity of relevant muscles can facilitate follow-on performance in a skill. However, this may be due entirely to the establishment of an activity set.

9. It is uncertain how physical exertion interacts with other task and environment variables. Nearly all of the experiments cited used exertion as the sole independent variable.

3. RATIONALE AND DIRECTION OF THE PRESENT STUDY

The last conclusion is the most remarkable because it has such wide-ranging practical implications. Since so many experiments (all but one) employed exercise as the single independent variable, the effects of exertion on skilled performance have been studied in isolation. This is an artificial situation and means that little of the laboratory research can be generalized to real world skills. As mentioned in the introduction, there are many factors that influence the level of competence in the countless activities humans perform daily. Not only do these variables affect skills in their own right, but various studies have demonstrated interactions between them (for a discussion, see Wickens, 1984). It is likely that exertion, too, interacts with some of these to affect performance. By combining exertion with other task factors, better generalizations can be made about real world skills.

As discussed earlier, one of the most potent contributors to skilled performance is anticipation. In fact, it is commonly held that true skill cannot exist without anticipation; acquisition of a skill means in part that one is now able to anticipate what comes next (Fitts, 1964; Holding, 1981; Poulton, 1957; Schmidt, 1968; 1982). Anticipation makes skills smooth, rapid, and accurate. This happens because one knows <u>what</u> to do <u>when</u>. A person continually receives information from the environment, and depending on the activity, certain cues are more relevant than others. Many of these cues are actually patterns of stimuli that let one predict the appropriate action ahead of time. So most behavior can be predecided and preloaded, to be carried

out in a continuous stream of activity. A good example is singing a familiar song to musical accompaniment. One does not wait to hear the notes before chiming in with the next measure. Rather, the singer knows from past experience/learning what comes next, both spatially-and temporally -- the pitch and tempo. The singing matches the music perfectly (assuming the ability to carry a tune!).

Anticipation is successful for a number of reasons. First, the person has learned what space and time cues are relevant. Second, for the most part these cues occur in a regular, predictable fashion. Third, the human information processing system can operate on new information as it is still handling the old. At its most complex level, one response may be undergoing execution while the next response is already being selected and, still further in advance, other information is being received and identified. This simultaneous processing is in harmony with multiple resource models of attention (e.g., Wickens, 1981; 1984), the capacity for parallel processing (Turvey, 1973), and very recent views of information processing: the cascade model (McClelland, 1979) and the continuous flow model (e.g., Eriksen & Schultz, 1979).

Knowing <u>what</u> will happen -- spatial anticipation -- lets a performer select and code the proper response ahead of time. A practical example is playing tennis. The ball comes over the net to the left or right of the player. Upon seeing this precue the player is able to select a forehand or backhand stroke well in advance of when it is needed. Experiments have shown that spatial anticipation produces faster, more accurate responses (Dorfman & Goldstein, 1975; Leonard, 1953; 1954; Poulton, 1952a). The classic experiment is a two-choice reaction-time

study where the subject knows in advance which response will be cued.

Temporal anticipation is knowing <u>when</u> an event will occur. This is sometimes known as coincident timing, which was discussed briefly in the literature review. A laboratory example is a simple reaction time task with a regular foreperiod, which allows a performer to make responses coincident with stimulus onset (Dorfman, 1977; Quesada & Schmidt, 1970; Slater-Hammel, 1960; Trumbo, Noble, Cross, & Ulrich, 1965). Practical examples are catching a ball or stepping onto an escalator.

There are several factors that determine how much can be anticipated or how effective it will be. These include the number of possible events (task complexity), the regularity or predictability of events (task coherency), the length of time that must be estimated, and the length of time available for previewing events. Generally, anticipation is better when the number of possible events is low, the events are highly probable, time intervals are short, and advance warning is sufficient enough to preselect a response (Klemmer, 1956; Poulton, 1952b; 1964; Schmidt, 1968; Whiting, Gill, & Stephenson, 1970).

The benefits of anticipating are many, and people use anticipation to great advantage. Witness a successful merge in heavy traffic, the home run in baseball, or shooting down an enemy aircraft. Yet there are costs of anticipating, too. For example, anticipation uses attentional resources (Kerr, 1975; Welford, 1976). Another cost becomes painfully evident when one considers that no event in the real world is totally predictable. This leads to anticipation that is incorrect and a subsequent response error: the right response at the wrong time, the

wrong response at the right time, or perhaps just "freezing" -- no action at all.

A few researchers have quantified the costs and benefits of anticipation. Posner, Nissen, & Ogden (1978) observed response times for correct anticipation that were substantially better than pure reaction times but saw slower times (by the same margin) when subjects' expectations of a stimulus were crossed. They also reported an increase in response errors when events were not as subjects had anticipated. Schmidt & Gordon (1977) specified the costs of anticipation more completely. Response errors occurred 64% of the time when anticipation was inaccurate, as opposed to 1% of the time when predictions were accurate. Further, when a response was in error, it added significantly to movement distance, since the subject began moving in the wrong direction. Stopping the move and recovering to zero, then completing the move correctly not only increased movement time, it decreased accuracy since subjects now had to move farther to a target. For trials where there was incorrect anticipation but no response error (the remaining 36%) subjects' response times were much slower -- nearly double that of correct anticipation conditions.

Anticipation, then, is a crucial factor in skilled performance and should be included in more investigations of skilled performance. In fact, by controlling for or eliminating a subject's anticipation many conclusions from experiments may not generalize to the real world (Turvey, 1977). Schmidt (1982) echoes Turvey's concern: ". . . by failing to recognize that stimuli are almost never suddenly presented, experimenters have uncovered a number of principles about human

performance that are unrelated to performance in natural environments." Because of the importance of this factor, the present study on the effects of exertion incorporated ideas on anticipation. Briefly, the investigation used a perceptual-motor skill that employed anticipatory elements. To reflect more of real-world requirements, the skill was performed under less than ideal conditions, i.e., there was more than one spatio-temporal pattern to recognize, anticipation was less than perfect, and the performer was under various physical loads that related directly to the task at hand.

The skill under investigation was a rapid, circular arm movement that was cued by a stimulus light. It was a ballistic cranking task that used anticipation to aid in the initiation of the response. This particular skill was chosen for a number of reasons. First, the literature reviewed for Quadrant II skills (of which this is a member) had the least consistent results; the area could profit from additional research. Second, research on local exertion and ballistic skills is sparse. Only four studies investigated this topic, and one of these was primarily interested in skill <u>acquisition</u>, not performance. Further, only one used multiple levels of exertion. Because local exertion with speeded tasks are common in the real world, the topic deserves more empirical work. Third, the circular motions of the task are important components of several common skills.

For the task, the direction of the move as well as the start time could be predicted by several precues, a situation similar to that of practical skills. Temporal and spatial anticipation were varied independently, and the manner in which they could be manipulated

reflected certain basic parameters in real-world situations. Specifically, coincident timing was based on a fast or slow sequence of precues. Spatial anticipation was less than ideal, acknowledging the uncertainty of real events. In the situation termed "normal" a sequence of spatial precues consistently predicted the direction of movement. In the "switched" situation, spatial precues unexpectedly switched halfway through the sequence, which forced the subject to revise his decision on the move. The normal sequences occurred far more often than the unpredictable sequences. All of this happened within the framework of multiple levels of local exertion. In sum, the experiment assessed performance of a discrete skill under very practical circumstances.

3.1 Experimental Design

There were three independent variables for the experiment. Their effects were measured by three dependent variables.

Independent Variables

Local Exertion (A). Four doses of arm/shoulder exercise at 20, 40, 60, and 80 percent maximum dynamic arm strength (which is defined in the procedure section). Exercise involved the specific muscles to be used in the subsequent skill. While it was impossible to prevent all systemic effects, the local exertion involved smaller muscle masses to reduce the overall impact on the body from such activity. The levels chosen reflected a realistic range of local exertion; in practice, people do not typically experience total rest or maximum effort but instead operate in the medium ranges.

Precue Speed (B). A fast or slow sequence of four lights (three precue, one stimulus). In the fast condition each light was on for 0.3 sec, in a sequence similar to a dragstrip start. The slow condition had each light on for 3.0 sec. Mowrer (1940) reported that longer intervals were harder to time, and Klemmer (1956) showed that extremely short intervals -- giving limited preview -- reduced the ability to deal effectively with all the information present. The specific durations used here were based on pilot work, which found these intervals could produce differential effects on coincident timing and error rate.

Stimulus Continuity (C). A normal trial had the light sequence begin and end in one row. A switched trial saw the sequence jump to the opposite row after two lights, finishing in the new row. Therefore, a switched trial contained only one spatially accurate precue (the third precue light) before stimulus onset. Normal trials occurred 80% of the time, which pilot studies found to be enough to induce an anticipatory set in the subject. In other words, a subject viewed a set of trials as quite predictable, so when a sequence switched, the performer was apt to respond slower or be more prone to an error.

Subjects received all levels of each factor, making this a 4 x 2 x 2 within-subjects design. The repeated measures design was employed for several reasons. First, pilot work revealed great variability across subjects in their reactions to exercise. The repeated measures design, therefore, greatly reduced error variance. Second, the design decreased the total number of training sessions (these were quite long), since

each subject participated in four sessions. Third, the combinations of anticipatory variables produced unique trial types, each of which had to be experienced by every subject if the anticipation factors were to make any sense.

Dependent Variables

Anticipatory Response Time (ART). The time from actual stimulus onset until the move began. The goal was to make the beginning of the move coincide with the onset of the last light in a sequence, the green stimulus light. ART was measured using two scoring systems. Constant error (CE) retains the sign of the score and is the arithmetic average error in responding. In this scoring system an ART could be positive or negative, and thus so could CE. The former meant a response after the green stimulus light came on, a late response. The latter meant a response before the stimulus actually occurred, an early response. CE is also known as response bias, a subject's tendency to behave a certain way. The second type of score, absolute error (AE), is more a measure of overall timing accuracy. It uses the absolute values of the timing deviations. Hence, early or late responding does not matter -- only how much off from the zero mark. Both scoring systems were in milliseconds.

Movement Time (MT). The time from the beginning to the end of the move. The movement required was a complete circle on a hand crank, clockwise or counterclockwise, followed by a short linear move to hit a target. MT was converted to velocity for certain performance comparisons. The goal was to make movement time (or velocity) as fast as possible.

Response Errors (ERR). An error was defined as either of two mistakes: starting the move in the wrong direction, i.e., the direction opposite of that indicated by the stimulus, or failing to hit the correct target at the end of the move. The goal was to minimize errors.

3.2 Research Hypotheses

The respective literature on physical exertion and anticipation implied certain relationships between the variables described above.

Anticipatory Response Time.

1. Timing is better for fast precue sequences than for slow ones.
2. Timing is better for normal trials than for switched ones.
3. Speed and Continuity interact. Specifically, fast, normal trials yield the best ARTs while fast, switched trials produce the worst. Slow trials, regardless of continuity, are essentially equivalent.

Movement Time.

1. Total MT increases as local exertion increases. Conversely, velocity decreases as local work increases.

Error Rate.

1. Fast trials lead to more errors than slow trials.
2. Switched trials produce more errors than normal ones.
3. Speed and Continuity interact. Specifically, there are more errors in fast, switched trials than in other trial types.
4. There are more errors as local work increases.

4. METHOD

4.1 Subjects

Subjects were volunteers from the Air Force ROTC detachment at North Carolina State University. All were right-handed males, ranging in age from 18 to 26. Of the initial 20 volunteers, 16 participants finished the experiment, and each of them received $50 for completing all 5 sessions.

4.2 Apparatus

Stimulus Mechanism. Refer to Figure 4.1. The apparatus was specifically designed to permit temporal and spatial aspects of anticipation to be varied independently. Two parallel rows of lights were mounted on a black matte-finish piece of bakelite. The bakelite was attached to a wooden frame so that the panel of lights slanted up 45 degrees from the horizontal. The rows of lights were 3" apart and within each row the lights were 2.5" apart. The top three lights in either row had red plastic covers while the last light in each row had a green cover (Radio Shack No. 272-325). The lights received power from a +5 VDC power supply. The entire light display sat on a wooden stand that was adjustable, so each subject had the optimum viewing angle for the stimuli.

Each of the eight lights was connected to a separate relay on a COMTEC peripheral processor (a small microcomputer with a Zilog Z8 microprocessor). This permitted programming the onset of lights in various patterns. For this experiment, three factors with two levels

each were used to create the possible light sequences:

Directionality ------------- left or right row

Duration (speed) ----------- 0.3 sec or 3.0 sec

Continuity ----------------- normal or switched

Hence, there were eight possible sequences that the peripheral processor generated (2 x 2 x 2). Appendix 8.2 contains more detailed plans for the stimulus mechanism, the connections to the peripheral processor, and the software developed to control the light sequences.

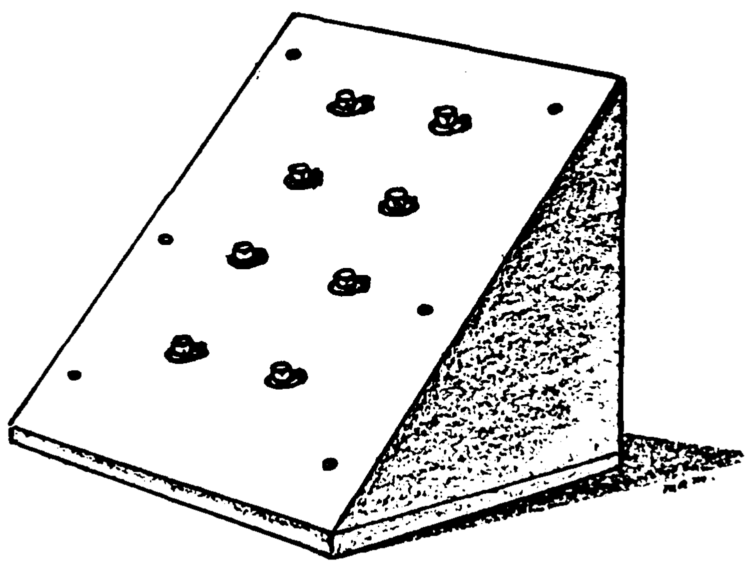

Figure 4.1. Stimulus Mechanism.

Response Apparatus. Refer to Figure 4.2. A specially designed response apparatus was constructed for this experiment. It was a freely-rotating hand crank that could rapidly measure position, movement time, or velocity at any point during a move.

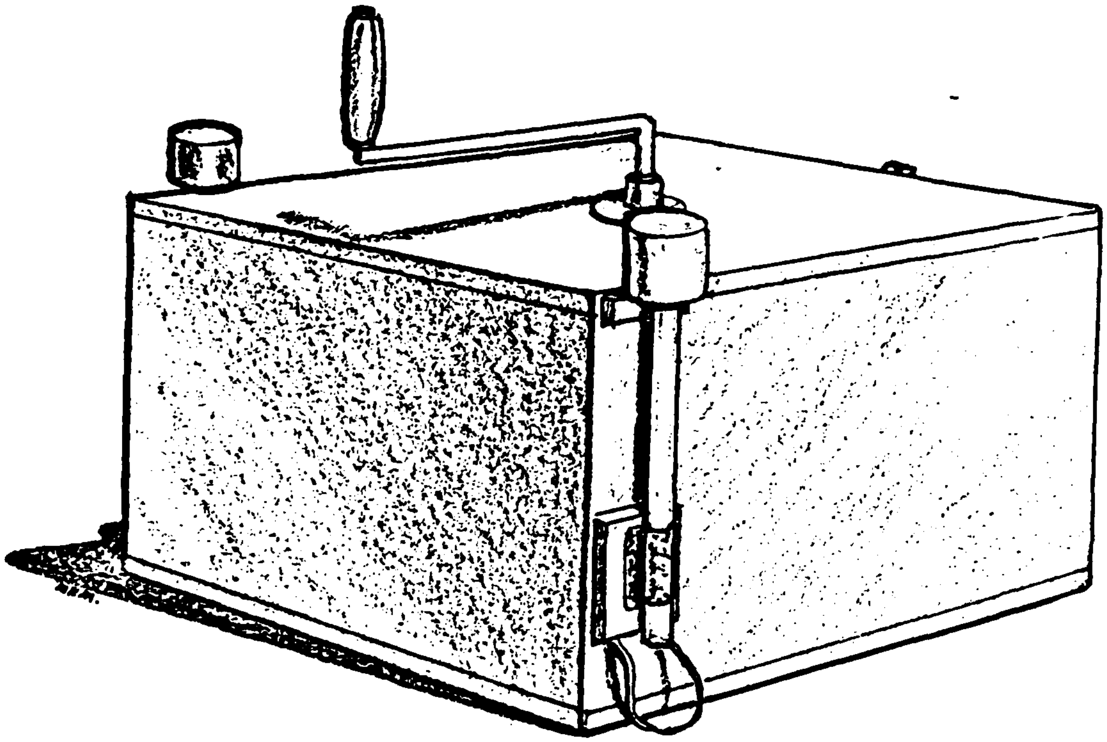

Figure 4.2. Response Apparatus.

The crank was machined out of 0.5" steel dowel. Its radius was 7.5" and it had a 5" vertical handle. The handle had a 4" wooden grip that swiveled easily about the metal dowel. The 10" shaft of the crank was mounted on two machine bearings which were bolted into 0.75" thick plywood at the top and bottom of a 17" x 18" x 9" wooden box. The box was secured to a wooden stand that permitted the height of the task to be adjustable.

Attached to the shaft of the crank was a 14.5" diameter, 0.0625" thick magnesium disk which rotated at the same angular velocity as the

shaft. This disk was drilled with an eight-bit binary pattern of holes. There was a distinct binary code every 4 degrees for a total of 90 uniquely identifiable positions about the circle. As the crank rotated, the disk passed through an optical scanner made of seven infrared lights (XC-880-A) and phototransistors (TIL 414). The digital pulse patterns from the scanner could be read, timed, and summarized by another COMTEC peripheral processor. This arrangement enabled collection of movement times and positions about the circle. For this experiment only general timing information was collected (for more details, see Appendix 8.2).

The disk hole at the 0 degree mark helped the subject quickly position the crank on the start mark. A circuit illuminated a small light when the hole was aligned between the infrared elements, i.e., when the crank itself was at the zero mark. Two digital clocks (Lafayette Instruments No. 54035) were wired into this circuit as well. The first began with the third precue light and stopped with the subject's first move away from the start mark. The second started with the subject's move away from the start mark and stopped when the subject hit a target at the end of the move. The target was a 2" high, 1.75" diameter foam cylinder that the subject hit with his right hand after turning the crank one revolution. One target was positioned at each top front corner of the crank box.

The specific response required for this experiment was a complete circle (approximately a 47" circumference) beginning and ending closest to the subject, followed by a 6" linear move to the target. Based on the green stimulus light this move either began to the right or the left and finished in the same direction.

Exercise Equipment. The basic equipment was a Monark 868 bicycle ergometer, specially modified for single-arm ergometry. A subject laid supine beneath the ergometer on a padded 75" x 27" table. This arrangement was necessary for two reasons. First, the Monark ergometer had a system of resistance that relied mainly on gravity, so it had to remain upright during cycling. This being the case, the subject had to be positioned under the ergometer and transverse to it in order to exercise arm and shoulder in the same plane as the movement required in the criterion skill. Second, a supine position for subjects helped isolate the local muscles because a subject could not easily employ other muscle groups (such as the legs) to assist in the work. This was additionally insured by the use of two automobile seatbelts -- one at the chest and one at the legs -- to immobilize the performer. In sum, arm/shoulder exercise in the described position promoted the use of relevant muscle groups while minimizing compensatory activity from other groups.

The ergometer was positioned transversely above the subject on a stand that was bolted to either side of the padded table (see Figure 4.3). The height of the table could be adjusted under the ergometer so that the subject's reach was optimal for the arm work. For rapid entrance and egress, the entire ergometer rotated on an axle attached to where its transport wheels had been. With this set-up it took less than 15 seconds to enter or exit the work station.

The left pedal on the ergometer was modified for hand gripping. The pedal was replaced with a steel shaft covered by a foam-padded hand

grip. The radius of the ergometer "crank" was 7.5", the same as the response apparatus. The subject cranked with his preferred arm, paced by a Wittner-Taktell metronome to maintain a speed of 50 rpm.

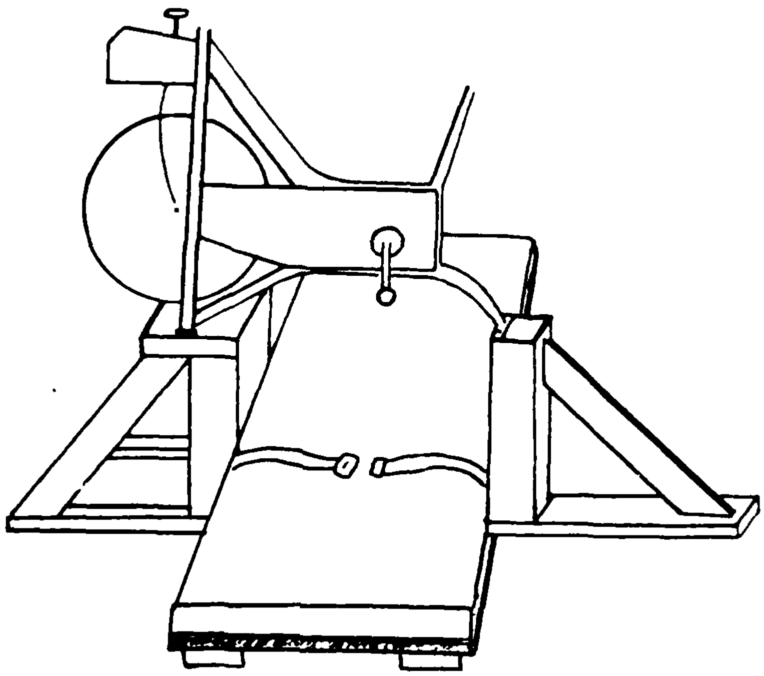

Figure 4.3. Exercise Station.

That the subject was supine for exercise but erect for the task was deemed to be of minimal physiologic consequence. Cummins and Gladdin (1983) studied arm ergometry above, at, and below heart level and found no significant differences in cardiovascular or metabolic response. They concluded that dynamic exercise could be performed in many positions without a significant change in bodily reactions.

But should the criterion skill have been performed in the same position? The answer depends on how much the legs and back contributed to task performance. For anticipatory response time and error rate, use

of the legs and back could not logically affect the skill. These measures reflect central information processing, and posture has no influence on such factors. For the third, movement time, there could have been some aid from these extra muscle groups. However, with a high-speed, circular move the legs and back best served a bracing role to permit the arm rapid movement about stationary coordinates. Any assist by these large muscle groups actually put the performer at a biomechanical disadvantage and movement time worsened. This was because when the entire body moved (as opposed to just the upper torso) there was more momentum to overcome, which made reversing direction slow and expended more energy. Hence, the bracing role of the back and legs was naturally superior, one typically preferred by subjects (which experimenter observations confirmed).

Microcomputer. A Zenith 150 microcomputer was used in the experiment to program and control the peripheral processor that ran the light sequences. The peripheral processor was connected to the microcomputer via a serial port. Via a software package, the keyboard on the microcomputer could be used to communicate with either the peripheral processor or the Zenith 150.

Rating of Perceived Exertion (RPE). On the wall at the foot of the exercise table was a 22" x 44" posterboard with the RPE scale on it (Borg, 1973; 1977). Lettering was black, with 2" numbers and 1" high verbal descriptors. Differentiated RPE was used as a manipulation check on exercise level. Pandolf (1977; 1978; 1982) has demonstrated that

such ratings are reliable and accurate measures of physical activity. With differentiated RPE, one rating is given for local exertion (in this case, arm and shoulder work) and another for central, systemic perceptions of exertion.

Equipment Layout. Refer to Figure 4.4. The equipment was arranged in a 10' x 13' section of the laboratory. The light display was located on a table in front of the standing subject, in direct line-of-sight. The crank housing sat on a wooden stand, and this assembly was positioned at one end of the table. The experimenter sat at the table, in front of the microcomputer. Approximately three feet behind and to the right of the subject was the exercise station.

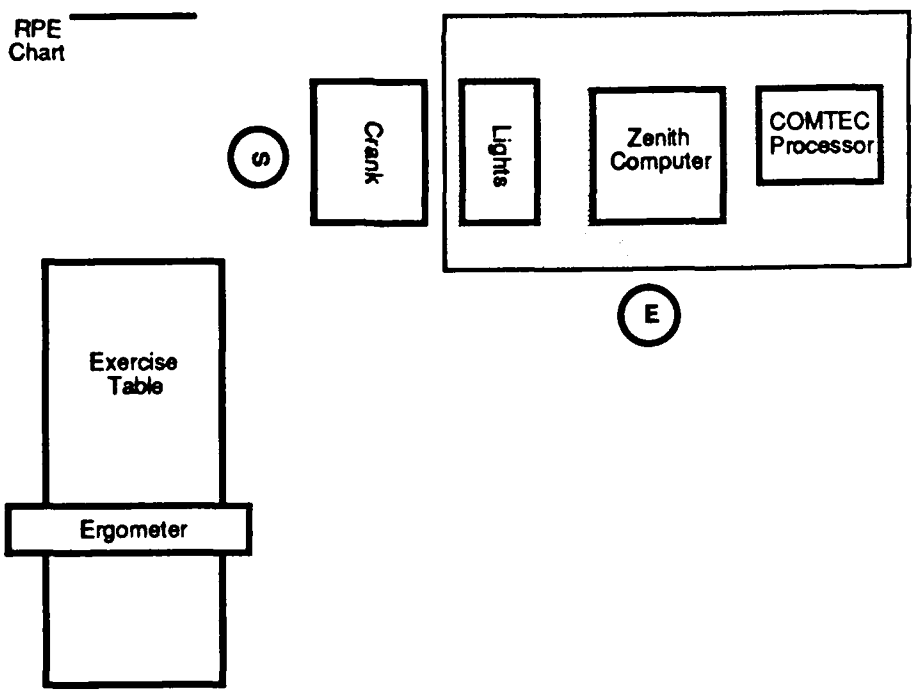

Figure 4.4. Equipment Layout.

4.3 Procedure

Screening and Training Session. There were several parts to this initial two-hour session. First, prospective subjects completed a brief questionnaire. Items dealt with anthropometry, prior injuries (to preferred shoulder, arm, or hand), diet (esp. caffeine and alcohol consumption), smoking habits, current medication, an estimate of health, an estimate of prior experience in sports and physical labor, and an informed consent block. A volunteer was disqualified if he had a prior injury to the preferred arm or shoulder or was under medication that would affect his performance. Upon completion of the questionnaire the participant was told not to smoke, eat, or drink at least one hour prior to experimental sessions. He was also told to abstain from consuming alcohol for the duration of the experiment.

Second, the subject received training on the criterion task. Standard instructions for the skill were read and the task was demonstrated (primary emphasis was on speed). Training proceeded in part-to-whole progression, with a two-minute rest approximately every ten minutes. The first 48 trials trained a subject on normal precue sequences and the subsequent responses. The next 40 trials trained him on the randomness factors -- that trial speeds and directions would be presented randomly and that 20% of the trials would be switched. The final 40 practice trials used mock exercise bouts on the ergometer, with a 2-minute workout at 0 kg given after every 4 trials.

The subject received a total of 128 practice trials. Verbal feedback in milliseconds was given for ART and MT after each trial. The

performer was also given suggestions concerning technique, in order to standardize it across subjects and make his performance optimal. The training was sufficient for all but three subjects to reach preset performance minimums. These three did not continue in the experiment and were dismissed at this point.

The last portion of the initial session was an assessment of individual capacity for local arm work. After the proper reach adjustments had been made on the exercise equipment, the subject was strapped onto the exercise table. He then cranked the ergometer at 50 rpm using the metronome to pace himself. The cranking resistance was increased by 0.1 kg increments until the subject showed obvious difficulty with the exercise load. At this point the resistance was held steady and he cranked for two minutes. The subject then rested for five minutes. If he had maintained 50 rpm for 2 minutes, he began exercising another two minutes with the top resistance increased by 0.1 kg. Otherwise, the resistance was lowered by the same amount and he tried at that load. The process was iterative, and its goal was to find the highest load that the subject could handle for 2 minutes at 50 rpm.

This level was labelled a subject's maximum dynamic arm strength. It should be noted that neither the method to find this level nor the term "maximum dynamic arm strength" are standard. This is so because no standards exist for local dynamic exercise (Åstrand & Rodahl, 1977). However, the method described was nonetheless systematic, repeatable, and able to account for individual exercise capacity.

The exercise bouts in the four experimental sessions were based on the maximum found in the screening session. These doses were defined by

holding rpm and duration constant and by varying only the cranking resistance. Thus, a person who established 1.5 kg as his top load had 0.6 kg of resistance for the 40 percent exertion condition, while a person whose maximum was 1.0 kg had 0.4 kg resistance in the same condition. Although the amount of absolute work was different, the relative exercise dose was the same for both people in the example above, and body reactions should have been equivalent.

Because the person's maximum capacity served as a benchmark for subsequent exertion levels, the assessment procedure was repeated (after a five-minute rest) until two identical maximum resistance readings were obtained. To encourage a subject to put forth a maximum voluntary effort, the instructions for this procedure strongly emphasized the importance of the experiment to the Air Force. In addition, the $50 payment for his effort was stressed.

At the conclusion of the screening session the subject made appointments for the four experimental sessions. To help control for circadian rhythm effects within each individual, each person scheduled his sessions at roughly the same time each day. Personal schedules did not permit exact scheduling, but a participant always stayed within a morning block, an afternoon block, or an evening block.

Experimental Sessions. There was one experimental session for each level of exertion (20, 40, 60, and 80 percent of maximum dynamic arm strength). A subject participated in only one session per day to allow the effects of exercise to totally dissipate. This minimized asymmetrical transfer effects from exercise. The different exercise intensities

given to subjects were counterbalanced to control for order effects.

Each session consisted of 40 trials, with 2 minutes of exercise interpolated every 4 trials. This prevented recovery and simulated the demands of ongoing activity found in real situations. A four-trial block lasted about one minute.

Since each subject participated in 4 sessions, he completed a total of 160 trials. To eliminate the learning of the sequence of 40 trials, four 40-trial sequences (A, B, C, D) were developed, and the subject experienced each only once.

The A, B, C, and D sequences contained the same basic elements: half the trials starting to the left and half to the right, half fast and half slow, 80% normal and 20% switched. A tabulation of trial types is shown in Table 4.1. The <u>order</u> of the eight types of trials was randomly determined within each 40-trial sequence. The four sequences (A, B, C, D) were counterbalanced within exertion level so each one appeared an equal number of times at all loads. Further, each order appeared an equal number of times in the first, second, third, and fourth sessions. Such counterbalancing eliminated systematic biases due to possible differences in the difficulty of the sequences.

Table 4.1. Summary of Trial Types per Session.

32 NORMAL	8 SWITCHED
16 Slow	4 Slow
8 Left	2 Left
8 Right	2 Right
16 Fast	4 Fast
8 Left	2 Left
8 Right	2 Right

A typical session proceeded as follows: The participant entered the laboratory and changed into gym clothes. He was then asked if there was anything that might seriously interfere with his performance (e.g., illness, severe muscle soreness). [Note: One subject admitted on his last day that he had had no sleep the night before. He was dismissed and none of his data were used. His disqualification left 16 subjects for data analysis.]

Abbreviated instructions were read each session to review the objectives of the task and the procedures in the exercise/trials cycle. The subject then performed a block of practice trials, which consisted of 12 trials for each of his first two sessions and 8 trials for each of his last two. This eliminated any warm-up decrement and established an activity set for the task.

At this point he began the initial exercise bout of two minutes, gave a differentiated RPE, and completed the first block of trials. This was followed by another exercise bout and a second block of trials, and so on, until the fifth block (trials 17-20). After exercising, the subject gave a second differentiated RPE, performed the fifth block of trials, then took a two-minute rest break. The session resumed with the exercise/trials cycle until the last block (37-40). Before trial 37 the subject gave a final differentiated RPE, then completed the block. If for some reason a particular trial had to be discarded (e.g., an unexpected interruption, a failure to respond), the trial was placed in a block later in the session.

Each trial was signalled by a verbal "Ready" command. One second later a precue sequence began, and the subject made his response at the

appropriate time. After each trial the subject's response time and movement time were announced (in milliseconds). Additionally, he was told if he had responded early or late to the green stimulus light. Approximately five seconds later a new "Ready" command was issued. After the fourth trial the participant proceeded to the exercise table, laid down, and fastened the seat belt(s). The ergometer was rotated into position and the metronome started. The transition averaged 20 seconds. At the end of the two-minute exercise bout, the ergometer was rotated out of the way and the metronome silenced. The subject unbuckled himself and transitioned to the task. These activities took an average of 15 seconds.

A session lasted approximately one hour. About 5 minutes of this were for instructions, 5 minutes for practice, 40 minutes for the task, and 10 minutes for recovery. At the end of the session the participant confirmed all remaining appointments.

After the subject completed the last session he was given a short exit interview concerning his reactions to the experiment. He was then debriefed and encouraged to ask any questions. Finally, he was thanked for his participation, paid, and dismissed.

5. RESULTS

Manipulation Check on Exertion. A person's rating of perceived exertion accurately reflects the level of work being done (cf. Borg, 1973; Hogan, Ogden, Gebhardt, & Fleishman, 1980; Stamford, 1976). Indeed, for this experiment the subjects' RPEs for local exertion correlated strongly with the actual work given ($r = .92$). Planned comparisons between the mean RPEs of adjacent work levels were carried out to see if subjects perceived each exercise level as different. The comparisons are shown in Table 5.1. All were significant ($p < .001$), which meant subjects felt they had exerted different amounts of effort for the four exercise doses. This was reliable feedback from subjects that the exertion levels produced distinct effects in them. For additional analyses of the RPE data, see Appendix 8.2.

Table 5.1. Planned Comparisons for RPE.

SOURCE	df	MS	F	p-value
Comp 1 (20% vs. 40%)	1	36.13	27.35	< .001
Comp 2 (40% vs. 60%)	1	63.28	74.90	< .001
Comp 3 (60% vs. 80%)	1	66.13	50.06	< .001
Error	45	1.32		

Analysis of Dependent Variables. Correlations between Anticipatory Response Time (ART), Movement Time (MT), and Error Rate (ERR) were computed. The correlation between each pair was low (see Table 5.2), and dependent measures were viewed as independent. This meant the proposed ANOVA model was appropriate.

Table 5.2. Correlations between Dependent Variables.

	MT	ERR
CE	-.17	.06
MT		.19

[CE scores for ART]

	MT	ERR
AE	.18	.01
MT		.19

[AE scores for ART]

As a precursor to the analysis of variance certain descriptive statistics were calculated. The range of CE scores for ART was -819 to +500 msec, and the range of MT scores was +244 to +999 msec. These were felt to be very broad ranges considering the ballistic skill used. There were also many outliers in the data (outliers for CE were defined as scores larger than + or - 200 msec from 0). Though these outliers will be treated in more detail later, their general effect was to inflate most of the standard deviations of the cell means to values that were greater than the cell means themselves. This resulted in skewed distributions. Based on this, tests for homogeneity of variance on the main effects of each independent variable were performed for ART and MT scores. Every test was significant ($p < .001$). A more detailed review of performance variability appears later in this section. For now, the results indicated a violation of the assumption of homogeneity of variance. This necessitated a data transformation so that the ANOVA could still be performed. ART and MT scores were transformed into ranks and the analysis of variance done on the ranked data using procedures developed by Conover and Iman (1981).

Anticipatory Response Time. A 4 x 2 x 2 repeated measures ANOVA revealed a main effect of Continuity ($F = 54.08$, $p < .0001$). The CE for normal trials was +13 msec and for switched trials was +40 msec. There was also a main effect for Speed ($F = 24.11$, $p = .0002$), with slow trials having a CE of −21 msec and fast trials +57 msec. The negative score indicates a response bias toward early starts, i.e., to begin the move before the green stimulus light came on. The data indicated that the bias in slow trials may have been due not only to starting early more often but also to more response initiations that could be called outliers, in other words, a greater number of very premature starts. These two ideas were statistically assessed via tests for differences of proportions. The first test compared the rate of early responses in the slow condition vs. the rate in the fast condition. The significant result ($z = 5.54$, $p < .0001$) confirmed the suspicion that slow trials induced more frequent early starts. As for outliers, the total of 1280 slow trials contained 157 with a response time earlier than −200 msec (about 12%). This compared to 7 of the 1280 slow trials that were later than +200 msec. Fast trials depicted a reverse trend: 2 trials were earlier than −200 msec while 72 (about 6%) were later than +200 msec. The key figure is that there were more than double the number of outliers for the slow trials as there were for the fast (regardless of sign), a statistic that was highly significant in a test for differences of proportions ($z = 10.19$, $p < .0001$).

The combination of Continuity and Speed produced a strong interaction ($F = 205.96$, $p < .0001$). Figure 5.1 depicts the interaction. Note also the large difference in scores between the

switched-fast and switched-slow trials. Table 5.3 (following page) summarizes the ANOVA for ART using constant error as the scoring method.

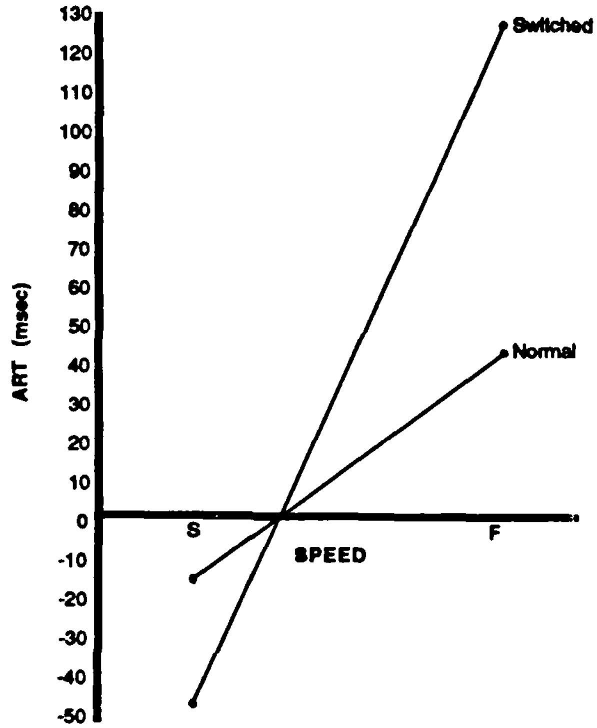

Figure 5.1. Continuity x Speed for ART using CE Scores.

The preceding analysis is somewhat misleading, however. Anticipatory response time performance can be defined as timing accuracy about a zero point, which in this case is the onset of the green stimulus light. Therefore, a response occurring 100 msec before stimulus onset has the same inaccuracy as a response 100 msec after stimulus onset. If these deviations are simply averaged, the mean is zero and timing appears to be excellent. The truth of the matter is that mean timing accuracy is 100 msec, which is obscured by the averaging of early and late responses.

Table 5.3. Summary of ANOVA for ART, using Constant Error Scores.

SOURCE	df	MS	F	p-value
A (exertion)	3	12,671	0.10	.9590
B (speed)	1	24,999,609	24.11	.0002
C (continuity)	1	5,352,355	54.08	< .0001
A x B	3	30,743	0.28	.8372
A x C	3	41,313	0.69	.5608
B x C	1	9,606,368	205.96	< .0001
A x B x C	3	7,754	0.13	.9416
S (subjects)	15	958,709		
A x S	45	125,454		
B x S	15	1,037,019		
C x S	15	98,967		
A x B x S	45	108,538		
A x C x S	45	59,570		
B x C x S	15	46,642		
A x B x C x S	45	59,495		
TOTAL	255			

Perhaps a more meaningful analysis is to use absolute error (AE) scores to give an idea of overall timing accuracy. When the ANOVA uses these scores, the F-ratios change somewhat (see Table 5.4). The greatest change is that the main effect for Speed disappears. Recall that the main effect for Speed was due to the -21 msec average response time for slow trials vs. the +57 msec mean time for fast trials. Also recall that the slow trials involved significantly more early responses. When these scores are now converted to deviations from the zero point -- the timing accuracy measure -- trial speed no longer has a main effect. The crux of the matter is that Speed does not produce a quantitative difference in timing accuracy. Rather, the speed of precues produces an important qualitative difference: early vs. late responding as a function of Speed. The most striking example occurs for the switched subset of trials. Only 7% of the fast trials had early responses, as contrasted with 39% of the slow trials. A test for differences of proportions was highly significant ($z = 9.04$, $p < .0001$).

As a comparison between AE and CE scores, the effects of Precue Speed are plotted in Figure 5.2. Note especially that Speed produces little effect on timing accuracy (AE scores), but it does manifest a response bias (CE scores). The interaction between Continuity and Speed (using AE scores) is depicted in Figure 5.3 and should be compared to the plot of the interaction using CE scores, shown in Figure 5.1. Of special interest in the figure is how the timing deviations diverge for the fast trials. AE is better for normal, worse for switched. It is also apparent from both figures that the main effect of Speed vanishes when timing is measured using absolute error.

Table 5.4. Summary of ANOVA for ART, using Absolute Error Scores.

SOURCE	df	MS	F	p-value
A	3	189,680	2.62	.0619
B	1	1,728,485	2.38	.1439
C	1	10,189,438	73.99	< .0001
A x B	3	135,585	1.47	.2362
A x C	3	43,953	0.89	.4518
B x C	1	6,048,064	63.30	< .0001
A x B x C	3	15,500	0.31	.8173
S	15	729,865		
A x S	45	72,266		
B x S	15	727,056		
C x S	15	137,709		
A x B x S	45	92,419		
A x C x S	45	49,184		
B x C x S	15	95,540		
A x B x C x S	45	49,830		
TOTAL	255			

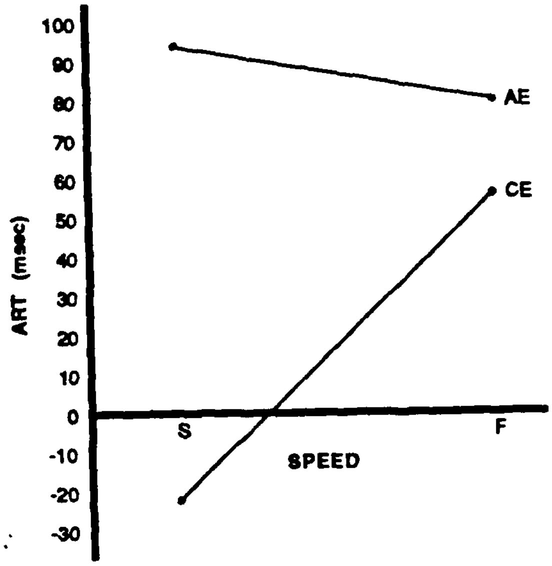

Figure 5.2. Main Effects of Precue Speed on ART using CE and AE Scores.

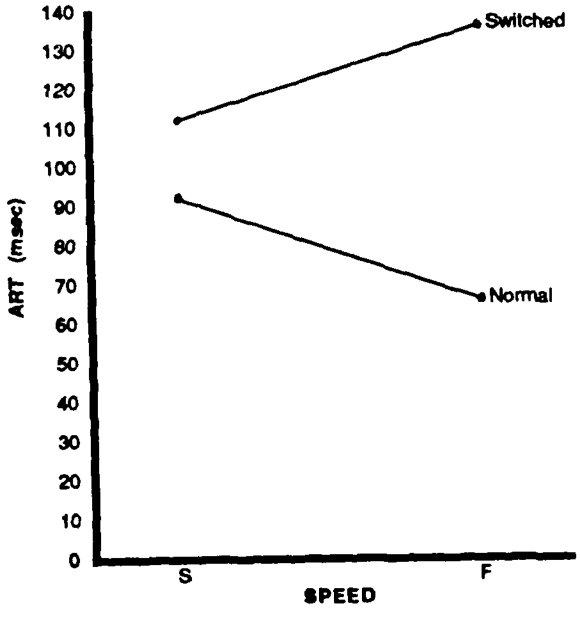

Figure 5.3. Continuity x Speed for ART using AE Scores.

Movement Time. A 4 x 2 x 2 repeated measures ANOVA was performed using ranks for the MT scores. Exercise produced a significant main effect ($F = 8.91$, $p = .0001$). A trend test was used to assess the shape of the Exercise-Movement Time relationship (refer to Figure 5.4). The test revealed a strong linear component to the curve ($F_{\langle lin \rangle} = 17.58$, $p < .0001$) and a significant quadratic component ($F_{\langle quad \rangle} = 4.37$, $p = .0422$). The cubic component was nonsignificant.

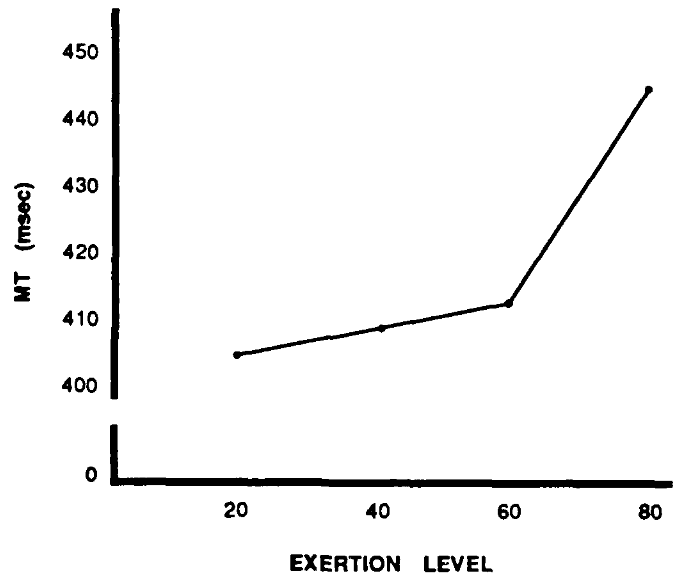

Figure 5.4. Main Effect of Exercise on Movement Time.

There was also a main effect for Continuity ($F = 6.08$, $p = .0262$). Normal trials had somewhat quicker MTs than the switched trials: 416 msec vs. 428 msec.

All other effects were nonsignificant. Refer to Table 5.5 for a summary of the analysis of variance on movement time. Supplemental analyses on the MT data are in Appendix 8.2.

Table 5.5. Summary of ANOVA for MT.

SOURCE	df	MS	F	p-value
A	3	2,340,376	8.91	.0001
B	1	459,049	3.04	.1015
C	1	496,667	6.08	.0262
A x B	3	53,391	0.87	.4638
A x C	3	43,554	1.25	.3019
B x C	1	371,605	3.52	.0801
A x B x C	3	77,276	1.56	.2122
S	15	3,198,495		
A x S	45	262,582		
B x S	15	150,846		
C x S	15	81,690		
A x B x S	45	61,387		
A x C x S	45	34,766		
B x C x S	15	105,487		
A x B x C x S	45	49,537		
TOTAL	255			

Error Rate. To review, an error on a trial consisted of either starting the move in the wrong direction or failing to hit the correct target. Four ERR scores were derived per session for every subject, one each for normal-fast, normal-slow, switched-fast, and switched-slow trial types. Since a subject participated in four sessions, 16 error scores were derived for him. Normal trials occurred four times more often than switched trials so statistical tests were based on error <u>rates</u> rather than on numbers of errors.

The data on errors were of a discrete nature and not normally distributed. Because of this, nonparametric methods were employed to analyze error rate. Unfortunately, nonparametric methods have not been developed for three-way designs. This limitation led to a conversion of the original experimental design (a 4 x 2 x 2). Continuity and Speed were collapsed into one factor, Trial Type, and the four possible combinations called "treatment conditions" of this factor (see Table 5.6). The conversion made the design a 4 x 4, so nonparametric analysis was possible without losing any information on the independent variables.

Table 5.6. "Levels" for the Trial Type Factor.

Switched-fast (s-f)

Switched-slow (s-s)

Normal-fast (n-f)

Normal-slow (n-s)

With the reorganization of the Continuity and Speed factors it became possible to test two hypotheses on main effects at the same time.

Recall it was thought that fast trials would produce a higher error rate than slow, and that switched trials would lead to a higher error rate than normal. Combining these hypotheses yields an ordering of trial types as follows:

$$\text{ERR (s-f)} > \text{ERR (n-f)} > \text{ERR (s-s)} > \text{ERR (n-s)}$$

The statistic used was the Jonckheere test for ordered alternatives, a more powerful procedure than two-tailed tests (Hollander & Wolfe, 1973). The results were significant ($J^* = 3.64$, $p < .0001$). Mean error rates, expressed as percentages, are in Table 5.7. Note that the error rate for switched-fast trials was approximately one in five and that this error rate was as much as three times higher than other trial types.

A Bradley Subtraction Test (Bradley, 1968) was performed to test for interactions. Only Continuity and Speed interacted ($H' = 4.7$, $p = .03$) and this is plotted in Figure 5.5. Note that except for the switched-fast condition, error rates for the trial types are close to each other.

Table 5.7. Error Rates for Trial Types.

TRIAL TYPE	ERROR RATE (percent of total trials)
Switched-fast	19.53
Normal-fast	8.11
Switched-slow	7.81
Normal-slow	6.45

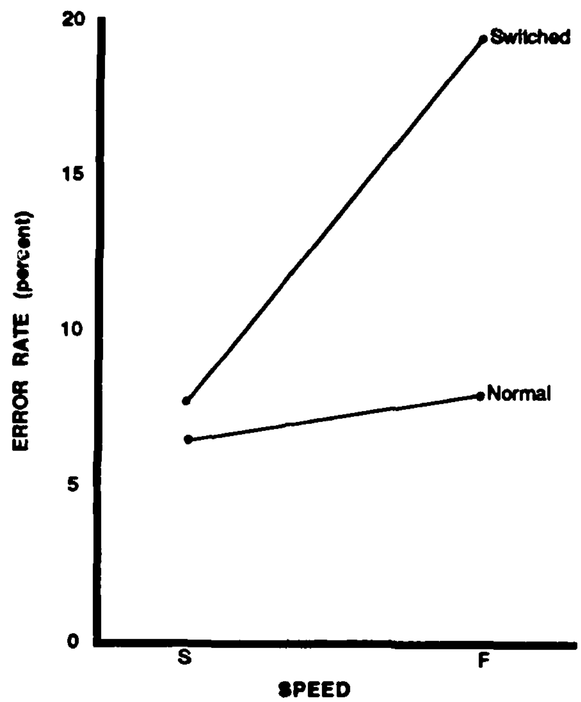

Figure 5.5. Continuity x Speed for ERR.

Exercise had no significant effects on error rate. Supplemental analyses for ERR are in Appendix 8.2.

Variability in Responding. Response variability corresponds to consistency of performance and may conceivably be as important as timing accuracy or the speed of movement, depending on task requirements. Variability was tested via Hartley's F <max> test (Bruning & Kintz, 1977).

F-tests on the ranked data indicated that Exertion did not affect Anticipatory Response Time or Movement Time, but this is not the complete picture. Variability in performance did increase as the

exertion level increased, both for ART (F <max> = 1.71, $p < .001$) and MT (F <max> = 1.51, $p < .001$).

Other independent variables also affected variability. For ART, switched trials had much more timing variability than did the normal trials -- more than double the variance (F <max> = 2.01, $p < .001$). Switched trials had greater variability in MT, too (F <max> = 1.63, $p < .001$). Finally, slow precues caused significantly more variance in timing as contrasted with fast precues (F <max> = 2.56, $p < .001$).

Several supplemental statistical procedures were performed on the data, most of which have been alluded to in the text above. While they were not crucial to the overall analysis or necessary for an understanding of the outcome of this experiment, they dealt with items of more than a passing interest. Refer to Appendix 8.2 for these additional procedures.

6. DISCUSSION

Discussion of the results begins with how the anticipatory variables influenced performance, followed by a consideration of the effects of local exertion. Finally, the findings will be generalized to practical circumstances, with emphasis on ergonomic applications.

6.1 Anticipation

All three response measures may be used to assess the effects of anticipation on performance, though ART and ERR are especially relevant. As discussed earlier, anticipation uses spatial and temporal elements together. However, since these aspects were manipulated independently and there were strong main effects for Continuity and Speed, it makes sense to discuss these variables separately before combining them.

Continuity. The main effect of Precue Continuity was as predicted; subjects demonstrated better timing for normal trials. CE scores were +13 msec for normal and +40 msec for switched trials, while AE scores were 79 msec and 124 msec, respectively. Thus, the switched trials caused a delay in the timed response, which is attributable to the spatial unpredictability in the switched condition. This is in harmony with general findings on spatial preview, which conclude that advance information facilitates responding when the precues are predictable (Leonard, 1953; 1954; Poulton, 1952a; Dorfman & Goldstein, 1975). These experiments have also found that unpredictable precues result in less than optimum performance; however, the advance information may still be used to some benefit. Degradation of performance for switched

trials can be also be seen in the data on timing variability. Switched trials had more than double the variance of normal trials. This may indicate that revising one's decision on a response, i.e., response reselection, interferes with the internal timing mechanism, a point which will be discussed in more detail later. In sum, timing was less accurate and less consistent when spatial information was unpredictable.

A second aspect of performance concerns the outcomes of incorrect anticipation, namely, errors. The results were as hypothesized; in fact, switched trials produced double the error rate of normal trials.

The increase in errors caused a more subtle outcome, one that stemmed directly from incorrect anticipation. Precue Continuity caused a main effect for MT, with switched trials having an average MT that was longer than normal trials. It is a mistake to think that a switched trial somehow slowed a person's ballistic move. Rather, what happened was that MT increased because movement distance increased, due to those trials in which a directional error was made. This is similar to what Schmidt & Gordon (1977) found for MT. The performer had to backtrack to the zero mark, then complete the move as it was supposed to be performed. On the surface, it appears that the magnitude of such movement penalties was not very great. The general MT means for Continuity were 416 msec for normal trials and 428 msec for switched. But the true size has been obscured by averaging all moves, those with and without directional errors. Splitting the switched trials into two MT means -- no directional error vs. directional error -- shows the actual size of the movement time penalty: 414 msec (no error) vs. 555 msec (error). Thus, when incorrect anticipation occurred because a trial was switched, it

led to more directional errors, and directional errors increased movement time by more than one-third (a 141 msec increase over 414 msec).

Conclusions on Precue Continuity are clear-cut. When an unexpected event occurs, performance is markedly worse. Response timing is less accurate (a greater deviation from zero) and more variable. Response errors increase considerably and there are substantial time penalties for moves begun in the wrong direction. These results imply that more than one central function is affected by spatial unpredictability. To be sure, the preplanned move must be discarded and a new set of instructions loaded for execution, all of which delays response execution. Response reselection appears to disrupt the reliability of the internal timing mechanism as well -- tests on timing variability support this. Also, not all preplanned moves can be changed, as is evidenced by the data on errors. This phenomenon may reflect a failure of information to even get into central processing, perhaps due to a lapse in attention. Additional comments on central effects are provided in the discussion of the Continuity x Speed interaction.

Precue Speed. At first glance the effect of Precue Speed was opposite that predicted. Subjects appeared to be closer to the zero mark during slow trials (reference the CE scores for Speed). But closer scrutiny reveals some unusual findings. Analysis of early vs. late responses, analysis of outliers, and even the negative CE score itself all point to a significant bias in responding for the slow trials, that of "jumping the gun." However, timing <u>accuracy</u> (as measured by AE scores), was not statistically different for either speed; the main

effect observed for CE scores disappeared when AE scores were used. [Note: Although the data failed to reach statistical significance, there was a difference in AE scores in the hypothesized direction. Fast trials had a mean of 81 msec and slow trials had a mean of 95 msec.]

The most interesting result is that the speed of the precue produced a qualitative shift in timing: more "late's" for fast precues and more "early's" for slow. Indeed, depending on the real world skill, this fact could be very important. Witness the baseball batter who swings late for a fastball but is way "out in front" on a change-up.

Analysis of variability supported the *a priori* ideas on Speed. Subjects were markedly less consistent when they dealt with slow precue sequences, producing two and one-half times the variance in timing.

Taken together, these findings agree with the conclusions of others, namely, that slower precues degrade coincident anticipation (Klemmer, 1956; Mowrer, 1940). A person's internal clock is apparently best suited for timing short intervals.

Another aspect of performance that Speed affects is the error rate. Again, the results were as predicted. Fast trials led to more errors, but note that the main effect here is due almost entirely to those fast trials that were also switched (refer to Figure 5.5). Errors increased in this situation most likely because the performer had little time to revise his intended move, an explanation which is in concert with experiments on the minimum preview duration needed for effective anticipation (Klemmer, 1956; Poulton, 1952b; 1957; Whiting, et al., 1970).

As a brief summary, the speed of information flow in an anticipatory situation produced a qualitative change in timing (response biases) but

no quantitative difference in overall accuracy. Timing consistency suffered in slow precue sequences, but fast sequences led to more errors, at least when the fast precues had an unexpected switch in them.

Continuity X Speed. Anticipation is, of course, a blend of spatial and temporal factors, so naturally the interaction of Continuity and Speed is of primary interest. The significant interactions followed predictions for ART (on both CE and AE scores) and ERR. More specifically, the accuracy in timing was the best (67 msec), as was the variance in timing, for normal-fast trials. Switched-fast trials were worst in accuracy, with more than double the AE score (136 msec). As hypothesized, the timing performance for slow trials fell between the two types of fast trials.

As predicted, errors were also worst for the switched-fast trials. The error rate was one in five (50 errors on the 256 switched-fast trials), which was two to three times that of other trial types. The two types of errors possible yielded different consequences. When the error was a directional one, it led to degraded performance in the form of a 34 percent increase in movement time. The second type of error, failing to hit the correct target, effectively meant a major goal in the skill was not reached. This type of error demonstrated that even if a programmed move started correctly, an error could occur before it was over. Such a mistake reflects an error in response execution, i.e., something went awry _during_ the move to cause the error.

The benefits and costs of anticipation obtained by the experimental manipulations are like those Schmidt & Gordon (1977) reported. The

benefits of good anticipation are well-timed, fast, accurate moves. The costs of incorrect anticipation are decreased timing accuracy, increased timing variability, a higher error rate, and longer moves. Depending on the task, it is apparent the costs of incorrect anticipation may be unacceptably high.

In what way do the anticipatory variables influence central processing mechanisms to produce the behaviors observed? The answer relies on information processing concepts as applied to the motor skills area.

Data on the skill learning phase of the experiment showed that the task was well learned by the end of the practice session. Given skill acquisition, some sort of motor program had been constructed by the participant. Such a program would have included, among other things, general instructions for which muscles should be activated (spatial information), the rhythm and sequencing of muscle firing patterns plus intervals for timing (temporal information), a set of stimuli for the skill, and a choice of force and speed parameters to insert into the general program (Keele & Summers, 1976; Schmidt, 1982). Motor programs are analogous to computer programs, complete with subroutines, parameter passing, rapid computations, and outputs. Just as for a computer, it takes time for a person to load a program from memory, insert real values in place of variables, compute an output, and transmit that output -- a series of muscle firing patterns -- to the body. The delay for this processing is known as the reaction time.

In highly learned activities, performance seems effortless and requires little attention. The performer has learned what stimuli may be expected for the skill, and motor outputs are pre-calculated for

upcoming responses based on familiar patterns of information unfolding in the present. This is anticipation, and it enables the proper response to be ready just as the stimulus occurs.

For example, as the first precue light came on, the subject immediately loaded a "wait" parameter into his program; his internal clock was set to time either 0.3 sec or 3.0 sec intervals. He also loaded the spatial and sequential parameters for a left or right move. In a normal-fast trial, all went well. The computations required to integrate all the factors for the move began with the first precue, and final instructions for the move were probably already loaded by the onset of the second precue -- 0.3 sec is just enough time to do this. The response thus prepared, the internal clock continued to count, doing an accurate job with the short intervals, until it was time to trigger the pre-calculated response.

But a <u>switched-fast</u> trial posed problems for the central processing unit. Only 300 msec before the planned response was scheduled to begin, the spatial information was changed. This necessitated cancelling the old response, loading new parameters for a different move, coupling these to the same "wait" parameter, computing new outputs, and getting ready to send the outputs to the muscles. Reworking major aspects of the planned move took time, and this was shown by the increased response latencies for the switched-fast trials. The response time was still better than a pure two-choice reaction time because certain aspects of the response remained predictable, most notably temporal anticipation (i.e., the speed of the precues). Because precue speed for the trial did not change once the light sequence began, a subject was still able

to do some advance processing (the "when" portion of the response) even if the row switched.

The above explanation accounts for responses where coincident timing was worse, yet where responses were still performed correctly. Sometimes, however, the subject failed to offload the original move and he carried it out in spite of altered precues. That the original plan was carried out means new information was unprocessed, i.e., the switched precues were seen but their meaning not processed. Why would this be so? As Kerr (1975) concluded, anticipation is attention-demanding. Conceivably, the advance processing of precues reached the limits of a person's attentional resources, so there was no additional capacity available the moment the unexpected event occurred (see Kahneman, 1973, or Wickens, 1984, for discussions). As a result, one of several things could have happened. One, the originally planned response was carried out, albeit a mistake. Two, the original response started, followed by a correction during the move. Three, the original move began, with a second error committed during the move as the information processing system became totally overwhelmed. Four, a response was attempted, but the performer gave up, again because capacity for further processing had been outstripped. Five, the move was begun correctly but not finished correctly, representing a delayed result of system overload. Six, the performer's systems were shut down temporarily -- "frozen" -- until the overload passed. Indeed, all of these behaviors occurred.

The fifth result is interesting because the error occurs after the move is in progress. That means some disruption to response execution was strong enough to override the motor program's pre-established

movement patterns. Indeed, the moves for the cranking task were long enough (a minimum of 400 msec) so that new instructions could have been computed and sent to the muscles -- this would have taken about a reaction time (200 msec). Hence, a target error may be a manifestation of an overloaded system mistakenly trying to amend a correct move.

Performance on slow trials was in between that of fast trials. On the whole, timing was not as good in slow sequences; switched trials especially seemed to affect timing. The tendency to respond early increased (the frequency of early responses climbed) and the magnitude of premature starts rose (the number of early outliers was much higher). In addition, the variability in timing was the highest for the switched-slow trials -- more than five times the variance of normal-fast trials. Perhaps recomputing the move (reselecting a response, etc.) disrupted the ongoing timing; the clock was already taxed by the difficult job of measuring a long interval, so it may have been sensitive to interference. Although timing performance declined, other aspects of performance improved in the slow precue condition. For instance, on those trials that were switched, error rates were lower than for switched-fast trials, probably because there was now enough time to attend to the precues, recompute the move, and check its correctness.

6.2 Local Exertion

Interpretation of the findings for exertion is straightforward. For ART, local work had no effect on CE or AE. Hence, neither timing accuracy nor bias were affected by local exertion, even when the exertion was heavy. This conclusion agrees with Bard & Fleury (1978)

and Fleury et al. (1981). Both of these studies used intense general exercise prior to a coincident timing task, and neither found any effects from the exertion.

Local exertion did not affect error rate either, which was contrary to predictions. In retrospect, the hypothesis placed too much emphasis on the role of the exercised limb, with the thought that excessive local exertion would make precise movements sloppy and error-ridden. Instead, the data implicate breakdowns in central processes as being responsible for most errors. Errors came from failures to code spatial information and reselect a response, or in mistakes in programming the move (be they before the move began or as a faulty correction to an ongoing move). With central processing producing most of the errors, it is reasonable that local exercise would have no effect on this response measure. Many other experiments on exertion also reported no effects on central information processing (e.g., Bonnet, 1980; Dechovitz, et al., 1974; Elbel, 1940; Higgins, et al., 1982; Kroll, 1973; 1974; McGlynn, et al., 1977; 1979; Meyers, et al., 1969; Phillips, 1963; Welch, 1969; Williams, et al. 1985).

Exertion also failed to produce any interactions with anticipatory variables. Though the findings here are nonsignificant, they are perhaps the most important results of this investigation. In point of fact, the question of whether or not exertion interacted with other task variables was the principle motivation behind this experiment. As far as the interplay of exertion and anticipation, the data clearly indicate there is no interaction. The lack of findings here may mean fewer statistical triumphs, but it conveys good tidings to all those in

physically-demanding skills. For the range of local exertion examined here, a performer's ability to anticipate probably remains unchanged, at least with respect to the temporal and spatial variables used in this study. To restate in more general terms, it appears that local exertion has little affect on cognitive functions.

The optimism must be tempered by the fact that timing variability increased with exertion, a finding that expands what Wrisberg & Herbert (1976) reported for static local exercise and general work. The experimental results on timing variability also relate to the data from the experiments on running, which found that the muscle firing pattern changed when the muscles were physically fatigued (Bates, et al., 1977; Elliot & Ackland, 1981; Sprague & Mann, 1983).

Local exertion increased movement time (decreased speed), which was hypothesized. The multiple levels of exertion permitted an assessment of the relationship between exertion and performance. The results failed to support an inverted U function. Instead, performance declined across all levels of exertion, with a dramatic drop (signalling the breakpoint had been surpassed) at the highest level.

Neither Exercise-Induced Activation nor the two-factor theory account for the experimental findings on MT. There was no rise in performance at any level. And it should be re-emphasized at this point that exertion produced no effects on ART or ERR, findings that are also at odds with inverted U theories. The best explanation for the data is also the most simple: muscular impairment. At low levels of exertion, aerobic processes succeed in removing wastes and supplying oxygen and energy to the muscles. As exertion becomes more severe, lactic acid

build-up exceeds waste removal. Oxygen and glucose are depleted from the blood. In addition, repeated firing of the motor units in the relevant muscles eventually lessens the muscles' readiness to respond. Given this explanation, it is reasonable to conjecture that muscle performance declined chiefly because of the cumulative effects of acute, local physiological processes.

Because variability in movement times was relatively small, a muscular impairment view may explain this effect, too. Muscle spindles are special proprioceptors that provide sensory information about changes in the length, tension, and contraction velocity of muscle fibers. Their function is to detect and control changes in muscle fibers, providing rapid regulation of movement (McArdle, et al., 1981). Such movement regulation involves the myotatic control loop. Via this reflex loop, the cerebellum can make small, automatic corrections to moves as often as every 30-50 msec (Schmidt, 1982). If the spindles become distorted by excessive stretching or contraction of the muscle fibers, the information they relay to the cerebellum will be inaccurate. Instructions from the cerebellum for the timing and patterning of motor unit firing will be based on this false feedback. An increase in movement variability (including movement time) would result.

In this experiment, the influence of exertion on performance was confined mainly to the local areas affected by the exercise. This is consistent with the specificity principle discussed earlier. As exertion became heavier, decrements in local performance (i.e., arm speed) became more pronounced. Beyond this, there were few effects on the central processes. Such effects may surface only when intense

general exercise produces massive systemic changes in the body (e.g., severe blood glucose depletion, decreased oxygen supply).

6.3 Generalizations and Implications

As mentioned earlier, this experiment studied skilled performance under realistic circumstances. For example, moderate physical work of several intensities used the muscles that were involved in the criterion task. The skill required anticipation for optimum performance, though there was also an element of unpredictability in this advance processing of information. Such factors mimic certain real-world constraints, so the results on anticipation and exertion have strong implications for practical situations. But before any generalizations are made, the issue of statistical vs. practical significance needs to be addressed.

As a rough indicator of practical import, compare the best and worst group mean performances on each of the three dependent measures:

ART (AE) -- 67 msec vs. 136 msec

ERR -- 6.5% vs. 19.5%

MT -- 404 msec vs. 444 msec (due to exercise)
555 msec (due to directional error)

Not listed is the qualitative shift in timing revealed by the CE scores. The key here is not so much in the magnitude of the differences but in the <u>relative</u> effects the experimental treatments produced.

Though the experiment mimicked certain aspects of real skills, the laboratory simulation was actually a simple one: 1) the response

decision was but two choices; 2) there were only two speeds of information flow; 3) temporal predictability was constant once a sequence began; 4) the probability of a switched trial was set; 5) further, it was known to the performer; 6) laboratory controls eliminated other distractions; 7) the subject exercised for only 2 minutes at a time, for a total of 20 minutes per session. Given these laboratory-induced limits, the experimental results seem more striking.

Now picture real skills, where the above factors are not nearly as constrained. Of course, one may only speculate as to the size of the actual decrements in "worst-case scenarios" but the point is clear: simple manipulations of the independent variables in this study produced major changes in skilled performance. Similar (or perhaps even greater) relative changes in performance may logically be expected for a person engaged in a real skill and experiencing the same sorts of conditions.

Given that the findings ARE of practical significance, in what circumstances would the results apply? The following examples illustrate some practical applications, using perspectives from ergonomics.

Imagine a task where information flows to a person in a regular manner, e.g., an airplane pilot, radar technician, power plant control room operator, or even an automobile driver. In many circumstances the timing of a response is of utmost importance. If the information develops slowly, intervals are difficult to time and performance is less than optimal. For example, the amber caution light in many cities is four to five seconds long. In large part, drivers base their GO/STOP decisions on the timing of this interval, and often such decisions are in error -- the duration of the amber light is not as anticipated and

the car enters the intersection when the light is red. If one assumes that such behavior will continue despite all driver education, then the only alternative is to aid drivers in their decisions. This could be done by changing the slow, steady amber light to one that flashes. Four or five one-second onsets could help drivers' timing and possibly improve their decisions. The optimum blink rate and total duration of the amber light could be determined empirically, then fixed by national safety standards.

In other tasks, accuracy is the primary criterion. The data from the experiment indicated that when the unexpected occurs, response latency is longer and more errors are made. This was especially true when information flowed rapidly. In certain jobs (e.g., fighter pilot) these costs of incorrect anticipation may be unacceptable. One system modification would be to slow down the rate of information flow, since the data showed that switched-slow trials had essentially the same error rate as normal trials. A related solution is to provide more advance warning of an unexpected event, giving the operator time to modify his response selection. This idea is preferable if good timing is to be maintained, since information can still flow rapidly -- it just must reflect earlier system status. To provide advance warning, additions to systems could include sensors that pick up smaller changes in operating parameters, and detectors placed earlier in the process to be monitored. NASA accident investigations have made it clear that such early detection subsystems were absent from critical components in the space shuttle Challenger. Had the "failproof" booster rockets been outfitted with early malfunction sensors, the crew might have been able to take

evasive action while a tragically unpredictable event was developing during the first 73 seconds of flight.

The ideal, of course, is to make the system totally predictable. The skeptic's first reaction to this suggestion is that it is an unrealistic goal, but various aspects of it are within reach. First, operators can be rigorously trained for all foreseeable contingencies, so that even if an unexpected event occurred, the information would be routinely (perhaps automatically) processed as just another possibility for the given circumstances. For example, military pilots and hospital personnel train for many months, drilling standard procedures for even remote possibilities. Their efficient actions during many unique events and crises attest to the efficacy of this strategy. Then, too, unpredictable events caused solely by equipment failures can be reduced through better system design, e.g., fewer components, more reliable components, redundant subsystems, early malfunction alarms, and automated responses to those unexpected events that are foreseeable by the system's planners. Other modifications have already been mentioned. Providing a longer preview for the operator would help the person anticipate surprise events from the environment. And incorporating predictor displays would let one better anticipate what effect a complex action might have. Such suggestions may significantly mitigate the performance declines demonstrated by the present investigation.

Local exertion had less effect on the dependent variables in this study, which means that fewer system modifications need to be made. The fighter pilot who is "pulling g's" in a dogfight should still be able to anticipate, i.e., to correctly select his shot and time his firing

despite the rigors of the manuevers. Likewise, the exhausted football linebacker should still be able to read the offense, anticipate the play, and decide whom to hit and when. Both performers, though, will undoubtedly be slower and less precise in their actual movements because local exertion affects the speed and variability of skilled responses. These conclusions must be made within the limits of the specificity principle, which states that the effects of physical work are largely confined to the muscles that have been exercised. Solutions to these problems include periodic rest breaks to allow recovery and decreasing the level of exertion experienced. For jobs with a constant workload, the performer's muscular strength and endurance could be increased as another way to deal with the physical demand.

6.4 Suggestions for Research

Research opportunities abound. It seems particularly relevant to examine anticipation in skilled performance, for this research would lead to a better simulation of real world tasks. Anticipatory variables can be combined with other contributors to skill, such as task difficulty, the use of strategies, S-R compatibility, and practice.

The two anticipatory variables used in this study (temporal and spatial) are prime candidates for future research, especially considering the powerful interaction they produced. Different precue speeds should be employed, and the temporal predictability should be manipulated. Varying task coherency -- the percent predictable -- for the spatial variable is another intriguing avenue for research. Various combinations of spatial and/or temporal predictability, plus the speed

of information flow could be used to mirror specific real-world tasks. At the basic research level, the combinations of different speeds and probabilities could be used to find optimum performance points and break-even points, plus uncover processing limitations.

As for local exertion, it appears that research should be confined to motor output processes, since effects on central information processing appear minimal. Of particular interest is how the characteristics of movements change as a function of local exertion. This involves the study of proprioceptive feedback and closed-loop control, motor output variability, and other potential changes in the components of a move -- timing irregularity, for example. Research along these lines would reveal more about the underlying mechanisms in movement control and show exactly what aspects of performance deteriorate under local work.

One largely untapped area is that of isometric exertion. This is unfortunate, since many office jobs contain large doses of static loading each day. More applied research should be carried out to ascertain how this form of exertion affects skilled performance, particularly for those tasks commonly undertaken in the office.

6.5 Summary

There were several important outcomes of this investigation. The major findings may be briefly stated as follows:

1. Local exertion did not interact with the spatial or temporal anticipation variables (Precue Continuity or Speed).

2. Local exercise produced one statistically significant result, that of a main effect on movement time. Arm movement speed decreased as the related arm work increased, with the performance decline accelerating as exertion became heavy. There was no evidence of an inverted U relationship between local exertion and any dependent variable.

3. Based on the above findings, it is reasonable to presume that local exertion has little, if any, effects on cognitive functioning. Rather, the effects of physical work appear to follow a specificity principle, whereby the effects of exertion on performance are limited to the muscles that have been exercised.

4. The speed and predictability of information showed a strong interaction. Coincident timing and response execution was very good when information flowed rapidly and was predictable. However, when information flow was rapid and unpredictable, there were major performance decrements: timing accuracy fell, timing consistency declined, and response error rate soared. The performance drop may be due to the problems the human information processing system has when it attempts to modify an anticipated response.

5. The speed of information flow created a response bias in coincident timing. Subjects exhibited a bias for early responding when information flowed slowly and a bias for late responding when precues were presented rapidly. These biases were amplified when information was unpredictable.

7. REFERENCES

Åstrand, P.O. & Rodahl, K. (1977). Textbook of work physiology: Physiological bases of exercise. New York: McGraw-Hill.

Babin, W.L. (1966). The effects of various loads on simple reaction latency as related to selected physiological parameters. Doctoral dissertation, University of Southern Mississippi.

Bard, C. & Fleury, M. (1978). Influence of imposed metabolic fatigue on visual capacity components. Perceptual and Motor Skills, 47, 1283-1287.

Barnett, M.L., Ross, D., Schmidt, R.A., & Todd, B. (1973). Motor skills learning and the specificity of training principle. Research Quarterly, 44, 440-447.

Barth, J.L., Holding, D.H., & Stamford, B.A. (1976). Risk versus effort in the assessment of motor fatigue. Journal of Motor Behavior, 8, 189-194.

Bartlett, F.C. (1943). Fatigue following highly skilled work. Proceedings of the Royal Society of London, B, 131, 247-257.

Bartlett, F.C. (1953). Psychological criteria of fatigue. In W.F. Floyd & A.T. Welford (Eds.), Symposium on fatigue. London: H.K. Lewis.

Bates, B.T., Osternig, L.R., & James, S.L. (1977). Fatigue effects in running. Journal of Motor Behavior, 9, 203-207.

Benton, M.E. & Bateman, R.P. (1980). The effects of left-hand fatigue on right-hand performance. In Proceedings of the 24th Annual Meeting of the Human Factors Society, Los Angeles, pp. 643-646.

Bonner, H.W. (1974). Preliminary exercise: A two-factor theory. Research Quarterly, 45, 138-147.

Bonnet, M.H. (1980). Sleep, performance, and mood after the energy expenditure equivalent of 40-hours of sleep deprivation. Psychophysiology, 17, 56-63.

Borg, G. (1973). Perceived exertion: A note on history and methods. Medicine and Science in Sports, 5, 90-93.

Borg, G. (1977). Simple ratings methods for estimation of perceived exertion. In G. Borg (Ed.), Physical work and effort. New York: Pergammon.

Bradley, J.V. (1968). Distribution-free statistical tests. Englewood Cliffs, NJ: Prentice-Hall.

Bruning, J.L. & Kintz, B.L. (1977). Computational handbook of statistics. Glenview, IL: Scott-Foresman.

Christina, R.W., Fischman, M.G., Vercruyssen, M.J.P., & Anson, G.J. (1982). Simple reaction time as a function of response complexity: Memory drum theory revisited. Journal of Motor Behavior, 14, -301-321.

Conover, W.J. & Iman, R.L. (1981). Rank transformations as a bridge between parametric and nonparametric statistics. American Statistician, 35, 124-133.

Craik, K.J.W. (1948). The theory of the human operator in control systems: II. Man as an element in a control system. British Journal of Psychology, 38, 142-148.

Cummins, T.D. & Gladden, L.B. (1983). Responses to submaximal and maximal arm cycling above, at, and below heart level. Medicine and Science in Sports and Exercise, 15, 295-298.

Davies, B.T. & Ward, H. (1978). The effect of physical work on a subsequent fine manipulative task. Ergonomics, 21, 939-944.

Dechovitz, A.B., Shultz, R.K., & Sadoski, T.L. (1974). The effects of whole body exercise on choice-reaction time performance. In Proceedings of the 18th Human Factors Society Annual Meeting, Huntsville, Alabama, pp.476-479.

DeVries, H.A. (1959). Effects of various warm-up procedures on 100-yard times of competitive swimmers. Research Quarterly, 30, 11-20.

Dickinson, J., Medhurst, C., & Whittingham, N. (1979). Warm-up and fatigue in skill acquisition and performance. Journal of Motor Behavior, 11, 81-86.

Dorfman, P. (1977). Timing and anticipation: A developmental perspective. Journal of Motor Behavior, 9, 67-79.

Dorfman, P.W. & Goldstein, I.L. (1975). The effects of task coherency, preview, and speed stress on timing and anticipation. Journal of Motor Behavior, 7, 45-55.

Duffy, E. (1962). Activation and behavior. New York: Wiley, p.36.

Elbel, E.R. (1940). A study of response time before and after exercise. Research Quarterly, 11, 86-95.

Elliot, B. & Ackland, T. (1981). Biomechanical effects of fatigue on 10,000 meter running technique. Research Quarterly, 52, 160-166.

Evans, W.O. (1966). Performance on a skilled task after physical work or in a high altitude environment. Perceptual and Motor Skills, 22, 371-380.

Fitts, P.M. (1964). Perceptual motor skills learning. In A.W. Melton (Ed.), Categories of human learning. New York: Academic Press.

Fleury, M., Bard, C., & Carriére, L. (1981). Effects of physical or perceptual work loads on a coincidence/anticipation task. Perceptual and Motor Skills, 53, 843-850.

Fleury, M., Bard, C., Jobin, J., & Carriére, L. (1981). Influence of different types of physical fatigue on a visual detection task. Perceptual and Motor Skills, 53, 723-730.

Gutin, B. (1973). Exercise-induced activation and human performance: A review. Research Quarterly, 44, 256-268.

Gutin, B., Fogle, R.K., Meyer, J., & Jaeger, M. (1974). Steadiness as a function of prior exercise. Journal of Motor Behavior, 6, 69-76.

Hammerton, M. & Tickner, A.H. (1968). Physical fitness and skilled work after exercise. Ergonomics, 11, 41-45.

Hammerton, M. & Tickner, A.H. (1969). An investigation into the effect of exercising particular limb-segments upon performance in a tracking task. Ergonomics, 12, 47-49.

Hayes, K.C. (1976). Reaction times, reflex times, and fatigue. In E. Simonson and P.C. Weiser (Eds.), Psychological aspects and physiological correlates of work and fatigue. Springfield, IL: C.C. Thomas, pp. 106-136.

Higgins, E.A., Mertens, H.W., McKenzie, J.M., Funkhouser, G.E., White, M.A., & Milburn, N.J. (1982). The effects of physical fatigue and altitude on physiological, biochemical, and performance responses. Office of Aviation Medicine Report No. FAA-AM-82-10, FAA Civil Aeromedical Institute, Oklahoma City, OK.

Hogan, J.C., Ogden, G.D., Gebhardt, D.L., & Fleishman, E.A. (1980). Reliability and validity of methods for evaluating perceived effort. Journal of Applied Psychology, 65, 672-679.

Holding, D.H. (1981). Skills research. In D. Holding (Ed.), Human skill. New York: Wiley.

Hollander, M. & Wolfe, D.A. (1973). Nonparametric statistical methods. New York: Wiley.

Howard, R.M., Shea, C.H., & Herbert, W.G. (1982). The effects of fatigue on the control of a coincident timing response. The Journal of General Psychology, 106, 263-271.

Kao, H.S., Wang, S.Y., & Chiu, J.C. (1978). The effects of differential exercises on a manual control task. Psychologia: An International Journal of Psychology in the Orient, 21, 11-15.

Karpovich, P.V. & Hale, C. J. (1956). Warming up and physical performance. Journal of the American Medical Association, 162, 1117-1119.

Kaufmann, D. & Ware, W.B. (1971). Effect of warm-up and recovery techniques on repeated running endurance. Research Quarterly, 48, 328-332.

Keele, S.W. & Summers, J.J. (1976). The structure of motor programs. In G. Stelmach (Ed.), Motor control: Issues and trends. New York: Academic Press.

Keppel, G. (1982). Design and analysis: A researcher's handbook. Englewood Cliffs, NJ: Prentice-Hall.

Kerr, B. (1975). Processing demands during movement. Journal of Motor Behavior, 7, 15-27.

Klemmer, E.T. (1956). Time uncertainty in simple reaction time. Journal of Experimental Psychology, 51, 179-184.

Kroll, W. (1973). Effects of local muscular fatigue due to isometric and isotonic exercise upon fractionated reaction time components. Journal of Motor Behavior, 5, 81-93.

Kroll, W. (1974). Fractionated reaction and reflex time before and after fatiguing isotonic exercise. Medicine and Science in Sports, 6, 260-266.

Leonard, J.A. (1953). Advance information in sensori-motor skills. Quarterly Journal of Experimental Psychology, 5, 141-149.

Leonard, J.A. (1954). An experiment with occasional false information. Quarterly Journal of Experimental Psychology, 6, 79-85.

Levitt, S. & Gutin, B. (1971). Multiple choice reaction time and movement time during physical exercise. Research Quarterly, 42, 405-410.

Lybrand, W.A., Andrews, T.G., & Ross, (1954). Systemic fatigue and perceptual organization. American Journal of Psychology, 67, 704-707.

AD-A170 679 THE EFFECTS OF LOCAL EXERTION AND ANTICIPATION ON THE PERFORMANCE OF A DISCRETE SKILL(U) AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH B JAEGER 1986 2/2

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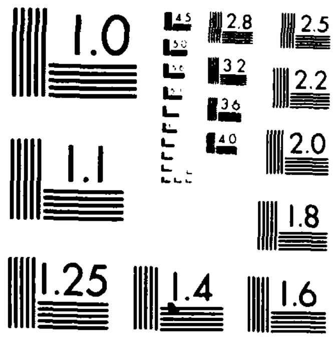

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Malmo, R.B. (1959). Activation: A neuropsychological dimension. The Psychological Review, 66, 367-386.

Massey, B.H., Johnson, W.R., & Kramer, G.F. (1961). Effect of warm-up exercise upon performance, using hypnosis to control the psychological variable. Research Quarterly, 32, 63-71.

Matthews, D.K. & Snyder, H.A. (1959). Effect of warm-up on the 40-yard dash. Research Quarterly, 30, 446-451.

McArdle, W.D., Katch, F.I., and Katch, V.L. (1981). Exercise physiology: Energy, nutrition, and human performance. Philadelphia: Lea and Febiger.

McGavin, R. (1968). Effect of different warm-up exercises of varying intensities on speed of leg movement. Research Quarterly, 39, 125-130.

McGlynn, G.H., Laughlin, N.T., & Bender, V.L. (1977). Effect of strenuous to exhaustive exercise on a discrimination task. Perceptual and Motor Skills, 44, 1139-1147.

McGlynn, G.H., Laughlin, N.T., & Rowe, V. (1979). The effect of increasing levels of exercise on mental performance. Ergonomics, 22, 407-414.

Meyers, C.R., Zimmerli, W., Farr, S.D., & Baschnagel, N.A. (1969). Effect of strenuous physical activity on reaction time. Research Quarterly, 40, 332-337.

Michael, E., Skubic, V., & Rochelle, R. (1957). Effect of warm-up on softball throw for distance. Research Quarterly, 28, 357-363.

Mowrer, O.H. (1940). Preparatory set (expectancy): Some methods of measurement. Psychological Monographs, 52, No. 233.

Nacson, J. & Schmidt, R.A. (1971). The activity-set hypothesis for warm-up decrement. Journal of Motor Behavior, 3, 1-15.

Nielson, D. & McGown, C. (1985). Information processing as a predictor of offensive ability in baseball. Perceptual and Motor Skills, 60, 775-781.

Pacheco, B.A. (1957). Improvement in jumping performance due to preliminary exercise. Research Quarterly, 28, 55-63.

Pandolf, K.B. (1977). Psychological and physiological factors influencing perceived exertion. In G. Borg (Ed.), Physical work and effort. New York: Pergammon.

Pandolf, K.B. (1978). Influence of local and central factors in dominating rated perceived exertion during physical work. Perceptual and Motor Skills, 46, 683-698.

Pandolf, K.B. (1982). Differentiated ratings of perceived exertion during physical exercise. Medicine and Science in Sports and Exercise, 14, 397-405.

Phillips, W.H. (1963). Influence of fatiguing warm-up exercises on speed of movement and reaction latency. Research Quarterly, 34, 370-378.

Posner, M.I., Nissen, M.J., & Ogden, W.C. (1978). Attended and unattended processing modes: The role of set for spatial location. In H.L. Pick & I.J. Saltzman (Eds.), Modes of perceiving and processing information. Hillsdale, NJ: Erlbaum.

Poulton, E.C. (1952). Perceptual anticipation in tracking with two-pointer and one-pointer displays. British Journal of Psychology, 43, 222-229. (a)

Poulton, E.C. (1952). The basis of perceptual anticipation in tracking. British Journal of Psychology, 43, 295-302. (b)

Poulton, E.C. (1957). On prediction in skilled movements. Psychological Bulletin, 54, 467-478.

Poulton, E.C. (1964). Postview and preview in tracking with complex and simple inputs. Ergonomics, 7, 257-266.

Richards, D.K. (1968). A two-factor theory of the warm-up effect in jumping performance. Research Quarterly, 39, 668-673.

Roca, J. (1980). Effects of warming up on reaction time and movement time in the lower extremities. International Journal of Sport Psychology, 11, 165-171.

Schmidt, R.A. (1968). Anticipation and timing in human motor performance. Psychological Bulletin, 70,631-646.

Schmidt, R.A. (1969). Performance and learning a gross motor skill under conditions of artificially-induced fatigue. Research Quarterly, 40, 185-190.

Schmidt, R.A. (1980). Past and future issues in motor programming. Research Quarterly, 51, 122-140.

Schmidt, R.A. (1982). Motor control and learning: A behavioral emphasis. Champaign, IL: Human Kinetics.

Schmidt, R. A. & Gordon, G.B. (1977). Errors in motor responding, "rapid" corrections, and false anticipations. Journal of Motor Behavior, 9, 101-111.

Schmidt, R.A. & Wrisberg, C.A. (1971). The activity-set hypothesis for warm-up decrement in a movement-speed task. Journal of Motor Behavior, 3, 318-325.

Schmidtke, H. (1976). Vigilance. In E. Simonson & P.C. Weiser (Eds.), Psychological aspects and physiological correlates of work and fatigue. Springfield, IL: C.C. Thomas.

Sheerer, N. & Burger, R. (1972). Effect of various levels of fatigue on reaction time and movement time. American Corrective Therapy Journal, 26, 146-147.

Siegel, D. (1985). Information processing abilities and performance on two perceptual-motor tasks. Perceptual and Motor Skills, 60, 459-466.

Singer, R.N. & Beaver, R. (1969). Bowling and the warm-up effect. Research Quarterly, 40, 372-375.

Skubic, V. & Hodgkins, J. (1959). Effect of warm-up activities on speed, strength, and accuracy. Research Quarterly, 28, 147-152.

Slater-Hammel, A.T. (1960). Reliability, accuracy, and refractoriness of a transit reaction. Research Quarterly, 31, 217-228.

Sprague, P. & Mann, R.V. (1983). The effects of muscular fatigue on the kinetics of sprint running. Research Quarterly, 54, 60-66.

Stamford, B.A. (1976). Validity and reliability of subjective ratings of perceived exertion during work. Ergonomics, 19, 53-60.

Swegan, D.B., Yankowski, G.T., & Williams, J.A. (1959). Effect of repetition upon speed of preferred-arm extension. Research Quarterly, 29, 74-82.

Thompson, H. (1959). Effect of warm-up upon physical performance in selected activities. Research Quarterly, 29, 231-246.

Trumbo, D., Noble, M., Cross, K., & Ulrich, L, (1965). Task predictability in the organization, acquisition, and retention of a tracking task. Journal of Experimental Psychology, 70, 252-263.

Turvey, M.T. (1977). Preliminaries to a theory of action with reference to vision. In R. Shaw & J. Bransford (Eds.), Perceiving, acting, and knowing. Hillsdale, NJ: Erlbaum.

Welch, M. (1969). Specificity of heavy work fatigue: Absence of transfer from heavy leg work to coordination tasks using the arms. Research Quarterly, 40, 402-406.

Welford, A.T. (1976). Fundamentals of skill. Glenview, IL: Scott-Foresman.

Whiting, H.T.A., Gill, E.B., & Stephenson, J.M. (1970). Critical time intervals for taking in flight information in a ball-catching task. Ergonomics, 13, 265-272.

Wickens, C.D. (1981). Processing resources in attention. Office of Naval Research, Report No. EPL-81-3/ONR-81-3 (NTIS No. AD-A102719), Arlington, VA.

Wickens, C.D. (1984). Engineering psychology and human performance. Columbus, OH: Charles Melville.

Williams, L.R.T., Pottinger, P.R., & Shapcott, D.G. (1985). Effects of exercise on choice reaction latency and movement speed. Perceptual and Motorr Skills, 60, 67-71.

Wrisberg, C.A. & Herbert, W.G. (1976). Fatigue effects on the timing performance of well-practiced subjects. Research Quarterly, 47, 839-844.

8. APPENDICES

8.1 Description of Equipment

This appendix contains a more thorough explanation of the stimulus mechanism and the response apparatus. It is an informal narrative of why I chose the particular configurations described below, how I assembled the equipment, and suggestions for improvement. Be advised that this dissertation is copyrighted and any use of the plans (for reproducing or patenting the equipment) needs written permission from the author. Let me start by giving an overview of why I built this equipment, its major components, and what the system can do.

The hand crank is a general piece of motor skills equipment. It can measure complete circular movement, or simply movements in arc segments, both of which are components of many skills. It can render positional information at four-degree intervals and can use this information for high-speed computations involving time, distance, velocity, and acceleration. The means by which the apparatus does this is a custom-made optical scanner (my original design) that is interfaced to a dedicated microcomputer. The crank can be used in motor memory experiments, reaction time experiments, motor programming studies (either using constant velocity or constant distance paradigms), motor output variability work, and many other motor skills topics.

The stimulus equipment is somewhat simpler, but also is a piece of apparatus with general applications. It contains a series of eight lights, four in each row, that may be turned on in any sequence or

pattern. Available patterns total 256, while the timing of light sequences is infinite -- it only depends on the intervals chosen by the experimenter. As an aside, the light configuration does not need to remain in a 2 x 4 matrix but could be in any arrangement. Further, there need not be three red and one green light in each row. The mechanism is generally suited for the presentation of complex stimuli, for experiments dealing with pattern recognition, coincident timing, reaction time, motor programming, and so forth.

At the outset, I make no apologies for the items described in this appendix. I recognize that there are improvements possible for either piece of equipment. What I will be describing here are first generation prototypes, fairly primitive models, yet ones that worked flawlessly. Additionally, the equipment decribed here is what I consider the <u>least expensive</u> solution to fulfilling my specific needs for operational apparatus. Indeed, this was one of its chief merits. Most of the parts and techniques for assembly are within reach of a graduate student. I stayed away from more costly (though perhaps more accurate) "off the shelf" components because of budgetary constraints, and instead fashioned most of the components "from scratch" using miscellaneous hardware.

Table 8.1. Parts List for Stimulus Mechanism.

Item Description	Part	Qty
1" pine, 8 1/4" x 8 1/4"		1
1" pine, 10 1/2" x 8 1/4"		1
bakelite, 12" x 10 1/2"		1
lamp socket	Radio Shack 276-1997	8
#1847 6.3 V 150 mA lamp	Radio Shack 272-1115	8
SPDT microminiature PC relay	Radio Shack 275-240	4
bus strip	Radio Shack 274-650	2
experimenter board	Radio Shack 276-170	1
5 VDC power supply		1
COMTEC microprocessor *		1

* Available from COMTEC Manufacturing, Inc.
1164 E. Oakland Park Blvd.
Ft. Lauderdale FL 33334

Assembly of the Stimulus Mechanism

See Table 8.1 for the parts used, and refer to Figure 8.1 for external dimensions of the enclosure. The box is primarily wooden, save for the faceplate of black bakelite. The sides of the box were two isoceles right triangles, 8 1/4" per side, cut from 3/4" straight pine. These were screwed into a 1" thick bottom piece of 8 1/4" x 10 1/2" straight pine. A 10 1/2" x 12" piece of bakelite was screwed to the front sloping edge of the wooden side pieces. Its slant was 45 degrees, which I found to be fairly effective at eliminating glare from overhead lights. Additionally, I painted the surface of the bakelite with a black matte paint once all the light socket holes were drilled. This further cut down on glare.

The holes for the light sockets were 5/8" in diameter. The rows were 3" apart (center to center) and holes within a row 2 1/2" apart (center to center). The center of the top holes began 2" from the top edge of the box. I put a 6.3 volt bulb in each of the sockets, which was somewhat above the 5 volts put out by the power supply, but it served to lengthen the life of the lamps. The power supply illuminated them quite brightly and no subject complained of difficulty in seeing either color light. The lamp sockets came with red and green screw-on covers. I used red ones for the first three lights in a row and green for the last light.

The lights were turned on and off by a COMTEC peripheral processor, a small microcomputer with a Zilog Z8 microprocessor. These microcomputers have a set of built-in relays which can be programmed

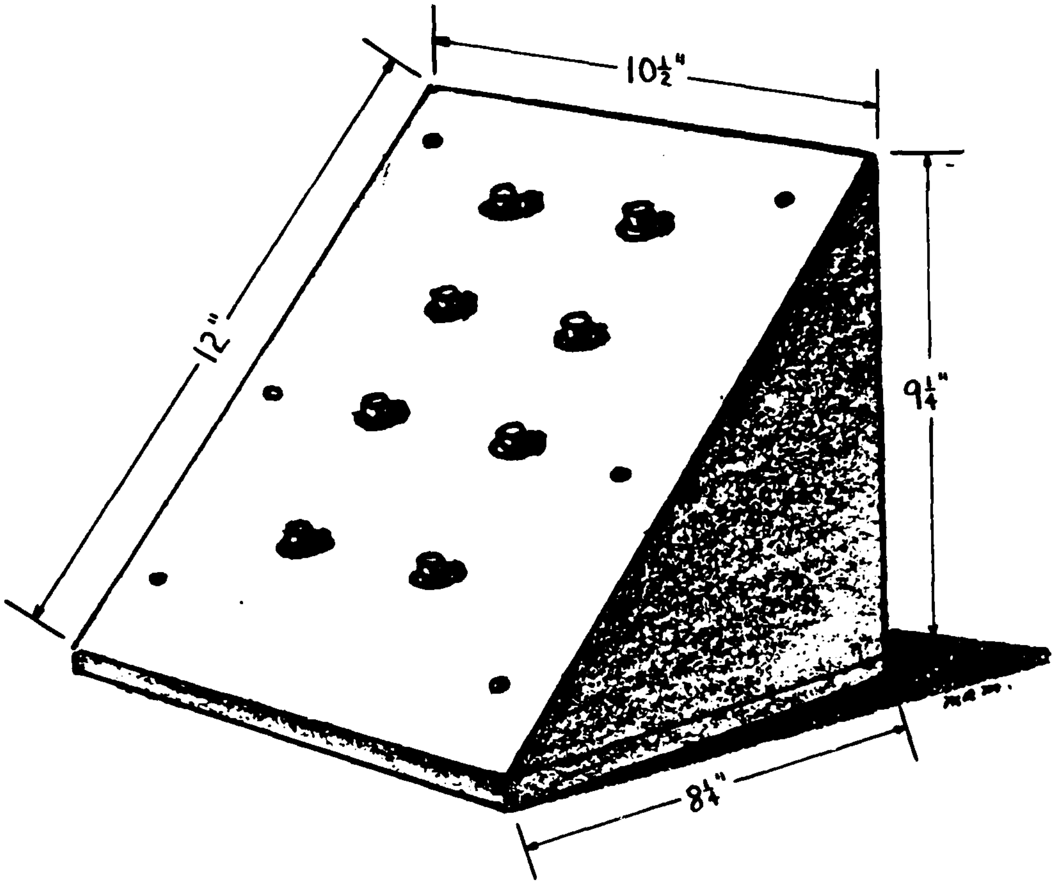

Figure 8.1. External Dimensions of Stimulus Mechanism.

using Tiny BASIC (this language is resident in ROM). The circuitry for each light thus involved a specific relay of the COMTEC processor, plus power from the 5 VDC power supply. The circuitry is depicted in Figure 8.2. Note particularly that there are four extra relays in the diagram. These were located inside the stimulus box and used to trigger functions on the Lafayette Instruments digital clocks. One relay set (two relays) was wired into the circuits that illuninated the first tier of lights, either left or right (light 1 or 2 -- see Figure 8.3). When either

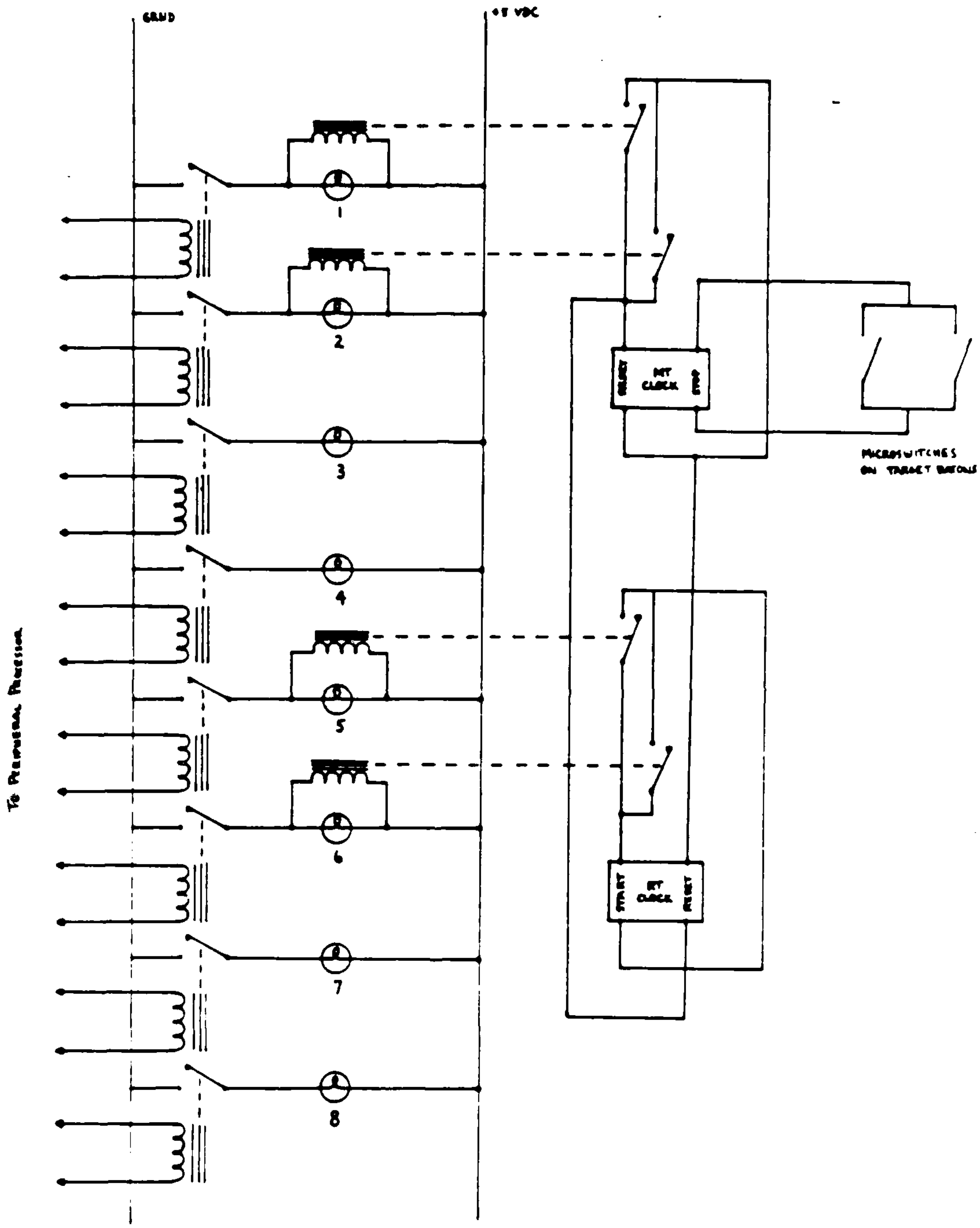

Figure 8.2. Wiring for Stimulus Mechanism.

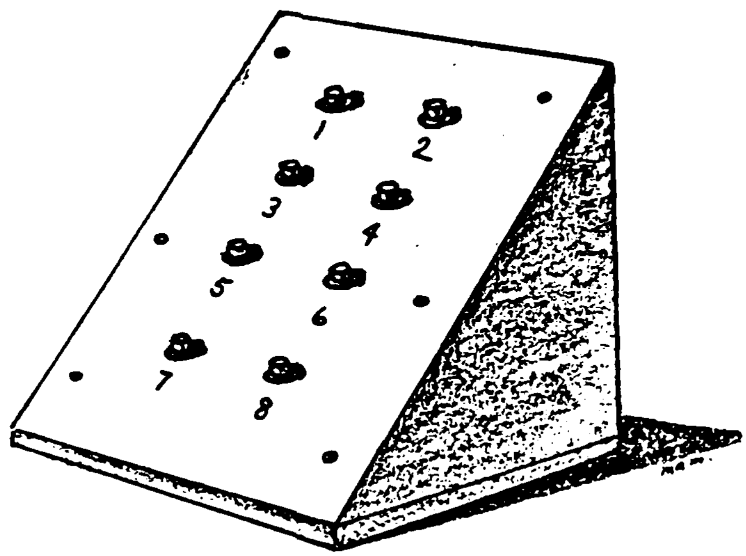

Figure 8.3. Numbers for Stimulus Lights.

light came on, the relay closed and this closed the contacts for resetting both digital clocks. Therefore, the digital clocks had an automatic reset built into the light sequence -- a very helpful addition to the circuit.

A second set of relays was wired into the circuits for lights 5 and 6 (third tier). These were connected to the Start contacts of the Anticipatory Response Time clock. This meant that the ART clock began <u>before</u> the green stimulus light came on. Such an arrangement was necessary because at times a subject would respond early, i.e., before the green light. To get a subject's actual response time, I merely subtracted the last interval (0.3 sec or 3.0 sec, depending on it being a fast or slow trial) from the clock time. If the result was negative, the participant had begun the move early. If positive, the move was

begun late. The magnitude of earliness/lateness was merely the result of the subtraction.

The software to program the light sequences was written in Tiny BASIC, a subset of Dartmouth BASIC (this is the only language the COMTEC processors can use). The short program did two things: 1) turned on the appropriate relays for normal and switched trials, for either the left or right versions; 2) counted intervals for the slow and fast versions of normal and switched trials (left or right). There was a total of eight trial types, therefore, and the computer simply accepted a number from 1 to 8, followed by a return, to run off a particular light sequence. These are listed in Table 8.2. Hitting a "9" ended the program.

Table 8.2. Key Entry to Computer for Specific Light Sequence.

1 -- normal fast left

2 -- switched fast left

3 -- normal slow left

4 -- switched slow left

5 -- normal fast right

6 -- switched fast right

7 -- normal slow right

8 -- switched slow right

Because of memory limitations and quirks in the way the Z8 microprocessor runs BASIC, the program I wrote was fairly user-hostile. There was no extra memory in the machine or I would have put in prompts

for the desired trial type, etc., plus comments. Nor was there room to put in many safeguards and error checks for things like keystroke mistakes on the experimenter's part. This was not as bad as it seems, because all one really did was to type in a single-digit number, then a return. I did not make a single mistake in doing this. A copy of the program (with documentation comments that should NOT be entered into the computer) appears in Table 8.3.

The peripheral processor was programmed easily by using a standard microcomputer as its terminal (since these small computers have no keyboard or disk drive of their own). I simply connected the COMTEC processor to a serial port on a microcomputer, then used a software communications package (e.g., Crosstalk, PC Talk) to convert the keyboard into one that the microcomputer and peripheral processor could alternately use. Via this method, a BASIC program stored on diskette could be quickly transferred to the peripheral processor, which saved me from having to type in the program anew each time the system was energized.

Table 8.3. Program for Light Sequences.

```
^B=%4000                                  (THESE FIRST TWO LINES JUST
NEW                                         INITIALIZE THE PROCESSOR)
5 GOTO 90
10 I=I+1
15 IF I<E GOTO 10
20 GOTO 60
25 J=J+1                                  (LINES 10-45 ARE THREE SEPA-
30 IF J<E GOTO 25                          RATE COUNTING LOOPS FOR THE
35 GOTO 65                                 TIMING DELAY OF EACH LIGHT)
40 K=K+1
45 IF K<E GOTO 40
50 GOTO 70
55 @%8000=A: GOTO 10                      (55-70 TURN ON THE SPECIFIC
60 @%8000=B: GOTO 25                       RELAY THAT IS CODED BELOW
65 @%8000=C: GOTO 40                       IN 100-800.  SEE NOTE.)
70 @%8000=D
75 L=L+1                                  (ANOTHER TIMING DELAY)
80 IF L<70 GOTO 75
85 @%8000=0
90 I=0:J=0:K=0:L=0                        (INITIALIZING VARIABLES)
95 INPUT T: GOTO T*100
100 A=1:B=4:C=16:D=64:E=13: GOTO 55           (EACH LINE REPRESENTS
200 A=2:B=8:C=16:D=64:E=13: GOTO 55            A SPECIFIC SEQUENCE
300 A=1:B=4:C=16:D=64:E=135: GOTO 55           OF LIGHTS, AS SHOWN
400 A=2:B=8:C=16:D=64:E=135: GOTO 55           IN THE NARRATIVE.  OF
500 A=2:B=8:C=32:D=128:E=13: GOTO 55           SPECIAL NOTE IS THE
600 A=1:B=4:C=32:D=128:E=13: GOTO 55           VALUE OF E -- A "13"
700 A=2:B=8:C=32:D=128:E=135: GOTO 55          IS ABOUT 0.3 SEC AND
800 A=1:B=4:C=32:D=128:E=135: GOTO 55          A "135" IS 3.0 SEC)
900 "ALL DONE"
```

NOTE: FOR LINES 55-70 A, B, C, D ARE VARIABLES THAT REFER TO THE TIER OF LIGHTS THAT WILL BE TURNED ON (see table below). THE RELAYS IN THE PERIPHERAL PROCESSOR ARE THE ON/OFF SWITCHES FOR THE LIGHTS. LINES 100-800 ASSIGN VALUES TO A, B, C, D AS TO WHAT RELAYS WILL ACTIVATE. THE DECIMAL NUMBER SHOWN LEADS TO A BINARY EQUIVALENT IN THE PROCESSOR THAT TURNS ONLY ONE RELAY ON AT A TIME. THESE CORRESPOND TO THE LIGHTS THUSLY:

A=1 ---- 0000 0001	FIRST RELAY ON	FIRST LIGHT ON
A=2 ---- 0000 0010	SECOND RELAY ON	SECOND LIGHT ON
B=4 ---- 0000 0100	THIRD RELAY ON	THIRD LIGHT ON
B=8 ---- 0000 1000	FOURTH RELAY ON	FOURTH LIGHT ON
C=16 --- 0001 0000	FIFTH RELAY ON	FIFTH LIGHT ON
C=32 --- 0010 0000	SIXTH RELAY ON	SIXTH LIGHT ON
D=64 --- 0100 0000	SEVENTH RELAY ON	SEVENTH LIGHT ON
D=128 -- 1000 0000	EIGHTH RELAY ON	EIGHTH LIGHT ON

Table 8.4. Parts List for Response Apparatus.

Item Description	Part	Qty
1" pine, 8" x 14 1/2"		2
1" pine, 8" x 17"		1
3/4" marine plywood, 17" x 18"		2
rubber feet		4
1/2" dia. steel dowel, 2' long		1
1/2" machine bearing	FAFN RA108RRB	2
flangette (mounting) for bearing	FAFN 40 MS-ZP	4
1/4" carriage bolt, 1" long		6
1 1/2" dia. wood dowel, 4" long		1
1/16" magnesium, 14 3/4" dia. disk		1
1/2" inner dia. solid shaft collar		2
3/32" steel, 2 1/2" x 2 1/2"		2
7/8" dia. PVC conduit, 10" long		2
foam pipe insulation, 2" long		2
screw eyelet		2
elastic band, 5" long		4
velcro strips		
subminiature SPDT lever switch	Radio Shack 275-016	2
1/2" wood block, 1/2" x 1"		2
1/2" wood block, 1" x 3"		2
4" x 4" post anchor		1
5/16" carriage bolt, 4" long		4

Table 8.4 continued

Item Description	Part	Qty
5/16" washer		16
5/16" nut		12
1 1/2" wood block, 4" x 4"		1
rubber pad, 4" x 4"		1
1/2" carriage bolt, 2 1/2" long		1
5/16" maple, 4" x 8"		2
1/4" pressed board, 4" x 8"		1
infrared emitter	Radio Shack 276-143	8
infrared phototransistor	Radio Shack 276-145	8
1/4 watt, 1k ohm resistor		8
1/4 watt, 250 ohm resistor		8
computer paper tape reader	OP-80A *	1
corner brace, 1 1/2" x 1 1/2"		2
8-lead wire, 12'		
10-lead wire, 12'		
experimenter board	Radio Shack 276-170	2
SPDT microminiature PC relay	Radio Shack 275-240	1
microlamps (pkg of 2)	Radio Shack 272-334	1
2N1711 transistor		1
1/4 watt 5.6k ohm resistor		1
5 and 12 VDC power supply		1

* Available from Oliver Audio Engineering
7330 Laurel Canyon Blvd.
North Hollywood CA 91605

Assembly of the Response Apparatus

This is a piece that appears brutish yet nevertheless has some sophistication to it. Because it can be used for all manner of circular movements, including very high speed moves, it had to be exceedingly sturdy. But it also had to be extermely smooth and fairly accurate, since it can be used for precision positioning.

I divided construction into several phases, and the parts list (Table 8.4) reflects this. I tried to build the apparatus as a unit composed of fairly independent subsystems, so that each could be removed without greatly affecting the others. I found this application of maintainability design to be of utmost value when working on the various components. Such an approach implies installing parts so they could be removed, which meant everything was put together and installed with screws. While more tedious to assemble initially, this approach was worth it in the long run. I also made important components adjustable: the height of the disk, the height of the crank, and the position of the entire optical scanner subsystem (in-out, up-down, left-right, and rotationally). The adjustability aspect of the equipment was absolutely indispensable.

Crank Housing. Refer to Table 8.4 for parts and to Figure 8.4 for the external dimensions of the box. The top, bottom, and sides of the box had to be cut with exactly square corners and straight edges, or the crank shaft would be crooked when mounted in the box. Before screwing the wood pieces together, I drilled a 5/8" hole for the shaft of the crank through the plywood top and bottom. The center of the hole was

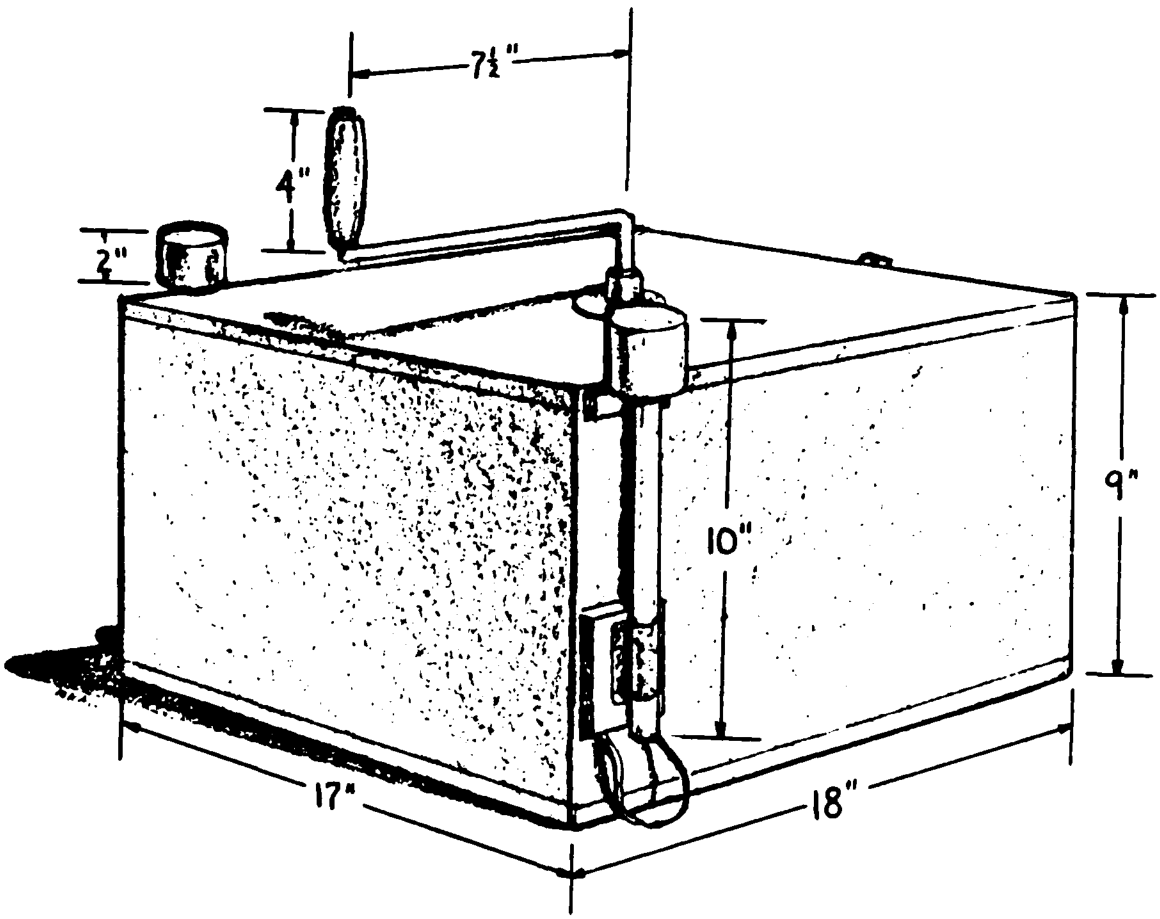

Figure 8.4. External Dimensions of the Response Apparatus.

8 1/2" from either side edge and 8 1/2" from the front edge of the plywood. Additionally, I drilled a 1 1/2" diameter depression in the TOP side of both the top and bottom box pieces. The depression was about 1/4" deep and had the same center as the hole previously drilled. The depression allowed for the seating of the machine bearing flangettes (i.e., the housing for the bearings).

The back of the box remained open for easy access to the items inside. I used 2 1/2" flat head screws to assemble the box. Before screwing the top piece to the three walls and bottom, I installed the top and bottom machine bearing assemblies (bearing plus flangettes) using the 1/4" carriage bolts. I then inserted the crank shaft and made sure it was vertical. Then I marked the lid, drilled holes, and screwed it down onto the box sides.

The steel crank itself was made at a machine shop. I chose a 10" shaft as a minimum length because of the various components that needed to go inside the box (see Figure 8.5). I chose a 7 1/2" radius because it was the same as the bicycle ergometer's. Also, it was a good radius for producing moves that involved an appreciable amount of time to complete, since the circumference of the circle prescribed by a 7 1/2" radius is about 47". The 5" vertical handle section of the steel dowel had a washer welded to the lower end, and the upper end was threaded for a 1/4" machine screw. A hand-fashioned wooden handle fit over this section, with the washer providing a stop on the lower end and the machine screw on the upper end. The handle was made from a 1 1/2" wooden dowel, 4" long. It had a 1/2" hole bored through the middle so the metal dowel fit through it. [Note: I reamed this out a bit so the

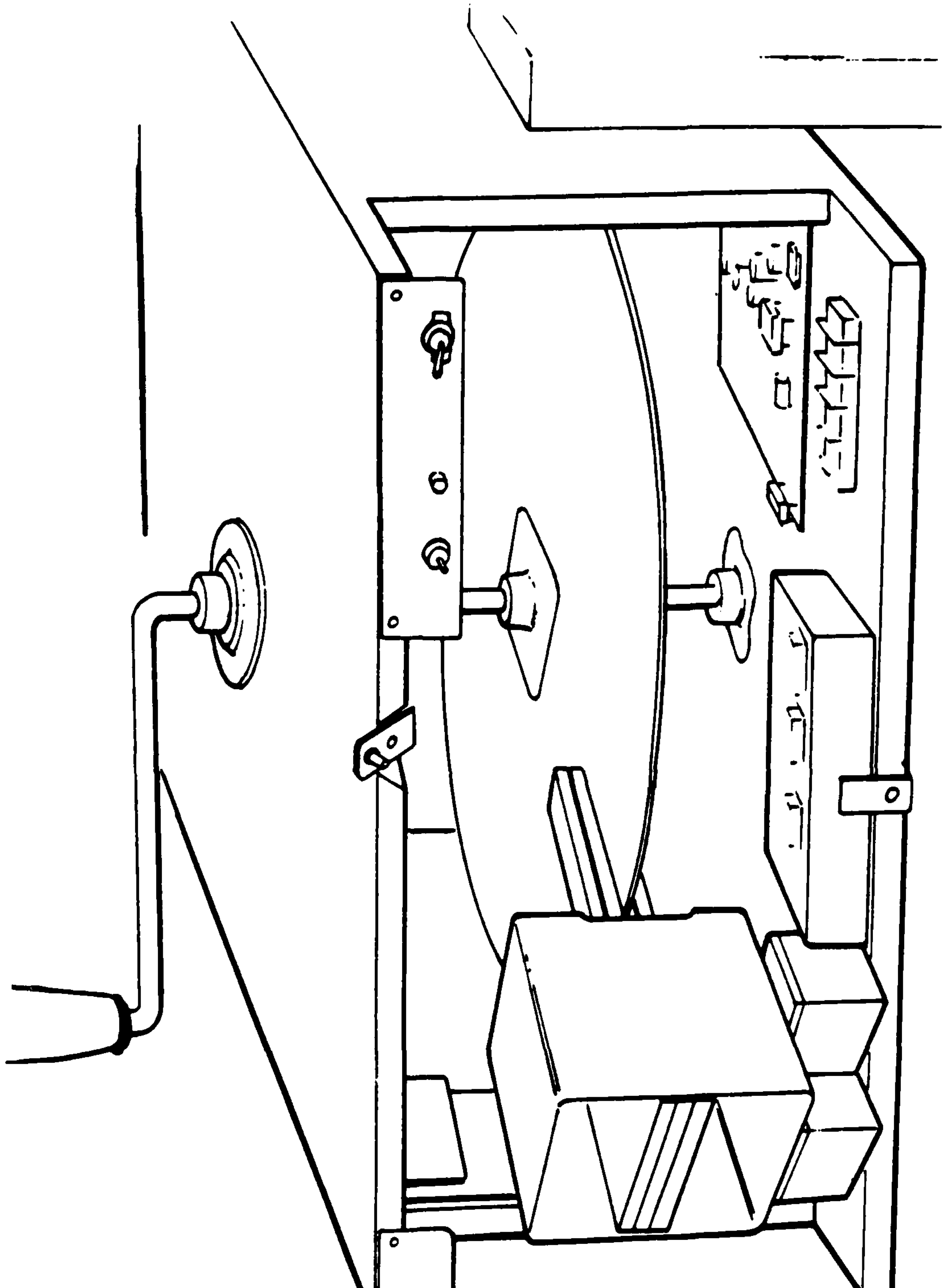

Figure 8.5. Components inside Crank Box.

handle swiveled freely about the metal dowel.] The handle was sculpted to conform comfortably to the hand. Talcum powder proved to be an excellent lubricant between the metal dowel and the wooden handle.

Because the machine bearing flangettes had to be installed with carriage bolts, the bottom of the crank box was not flat. I attached rubber feet on the bottom four corners so the box sat level during those frequent occasions when I removed the box from its stand to adjust the height of the stand.

Targets. The targets were 2" long foam cylinders that were mounted on PVC conduit to form what looked like a short baton. These batons were secured to the crank box with velcro. They served two purposes, one from the viewpoint of the experiment and a related, yet purely mechanical function.

The presence of targets at the end of the move permitted an accuracy measure to be taken in the experiment. In this respect, the size of the targets (diameter and length of foam cylinder) could be an experimental variable, though it was held constant in the present study.

Hitting a target moved the baton away from the crank box, which closed a microswitch and stopped the movement time clock. This was the mechanical function of the targets. There are other ways to stop the movement time clock (such as by having the hand pass through a light beam type "switch", or when the crank reached a certain position on the metal disk), but the manual method using targets attached to batons was the easiest, least expensive solution. And, as mentioned, this method permitted collection of error data while other solutions did not.

The batons themselves were 10"-long pieces of 7/8" (outside diameter) plastic pipe with a 2" length of foam pipe insulation lightly glued to one end. This 2" cylinder served as the actual target (the target was 2" high and 1 1/2" outside diameter). The bottom of the pipe had a double elastic band that was tied toward the rear end through a hole drilled in the side of the pipe. The other ends of the 5" long elastic cords were tied to a screw eyelet on the crank box. Thus, when a subject hit a target, the baton only traveled a limited distance from the box. The foam targets and elastic bands had to be replaced due to wear and tear about every 3000 trials.

Refer again to Figure 8.4. On the front left and right sides of the box were small blocks of wood, 1/2" thick. The top block was a 1/2" x 1" rectangular piece that had a strip of velcro glued along its length (fuzzy side of the velcro). The bottom block was 1" x 3", with velcro glued in a double-wide strip along its length. The corresponding hook part of the velcro was glued around the batons to match the velcro on the wood blocks. When properly positioned, the velcro glued to the batons enabled the foam targets to appear to be sitting just on the crank box top, at the very front corners.

On the top edge of each of the lower wood blocks was a microswitch, oriented horizontally and attached with brads to the block. Wires from these microswitches were run directly inside the crank box through holes in the box's sides. The width of the wood blocks (1/2") plus the velcro was such that when the baton was positioned against the blocks, the microswitch lever was pressed down. Conversely, when a target was struck it freed, or released, the lever. The left and right switches

were connected in parallel with the movement time clock, so that when either target was struck, a switch closed and the clock stopped. Notice that when the microswitch lever was in the up, or released, position the clock circuit was closed. [Note: The MT clock began when the ART clock stopped. The ART clock stopped when the crank was moved from the zero point, i.e., off the alignment mark.] Refer to Figures 8.2 and 8.11 for the wiring circuits of the two digital clocks.

Disk. The metal disk was one-half of the custom-built optical scanner. Though there are other ways to sense position (or velocity) about a circle, I chose an optical system because there was no mechanical wear on it, it could be digitally coded, it had a linear relationship between distance moved and distance recorded for all points of the circle, and it permitted multiple revolutions. A simpler device, such as a potentiometer, did not possess all these advantages. I chose to use a rather large metal disk so more positions could be identified. I drilled binary hole patterns in the metal disk every 4 degrees, meaning there were 90 uniquely coded positions about the circle. The holes I drilled were 3/16" diameter, though it seemed the system could operate well with smaller holes. Drilling smaller holes, say 1/8" or less, would permit more radii to be identified; of course, the limit for an eight-bit system such as this is 256 positions -- a resolution down to about 1.5 degrees. See Figure 8.6 for the bit pattern I used.

The pattern for the holes on the disk was a simple binary progression using seven bits. [Note: In actuality, this was an eight-bit system since the alignment light used one hole.] I began with an

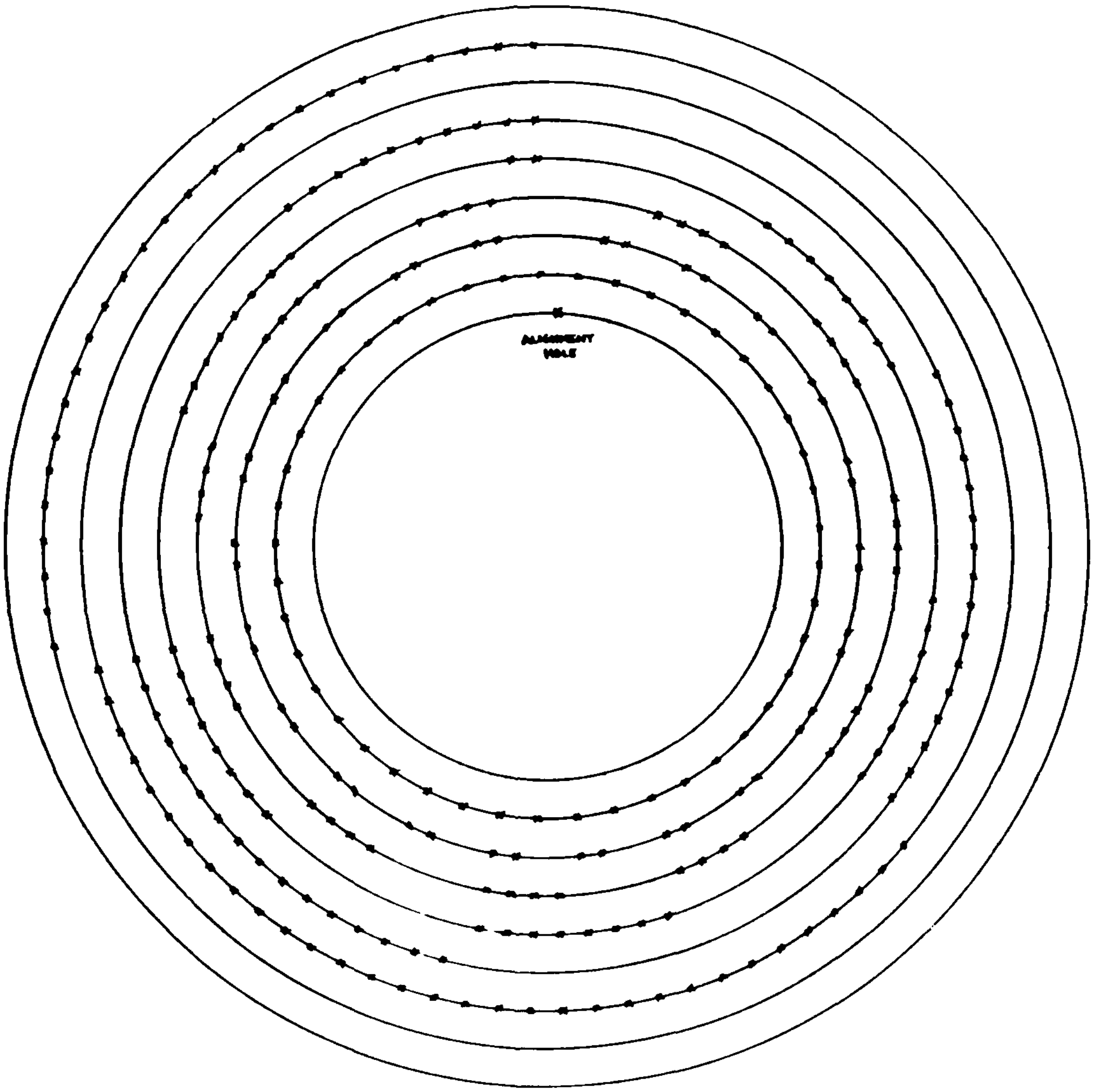

Figure 8.6. Markings for Holes on Magnesium Disk.

undrilled, 14 3/4" diameter magnesium disk made from magnesium sheet metal of 1/16" thickness. Magnesium is extremely light, strong, and warp-free -- characteristics not found in steel, aluminum, or other, more common metals. Thinness and lack of warp were needed so the infrared emitters and phototransistors could be placed close together (they were 1/4" apart in this system).

I drilled a tiny guide hole in the EXACT center of the disk, then marked off diameters directly on the disk every four degrees. Next I drew concentric circles onto the disk of the following radii: 4 4/8", 4 7/8", 5 2/8", 5 5/8", 6 0/8", 6 3/8", 6 6/8", 7 1/8". Each intersection of circle with diameter (720 intersections) represented a possible place to drill a hole. Using a sharp drill punch, I marked the holes to be drilled in accordance with Figure 8.6. Only after all the holes had been drilled did I drill the center hole for the crank shaft. This was a 1/2" diameter hole, equidistant from all concentric circles.

The disk was mounted on the shaft of the crank so that it turned without slippage on the shaft. I mounted a 1/2" solid shaft collar on a 2 1/2" x 2 1/2" piece of galvanized steel (3/32" thick) using a braised solder method -- I made two of these items. I then clamped the two pieces together and drilled a 1/2" hole through the steel plates using the shaft collars as a guide for the drill bit. I placed one of these mounting assemblies on either side of the disk, drilled a hole in each corner (through the magnesium disk, too) and screwed the pieces together with the disk sandwiched in between. The disk could now be attached to the shaft of the crank via the screws in the shaft collars (refer to Figure 8.7).

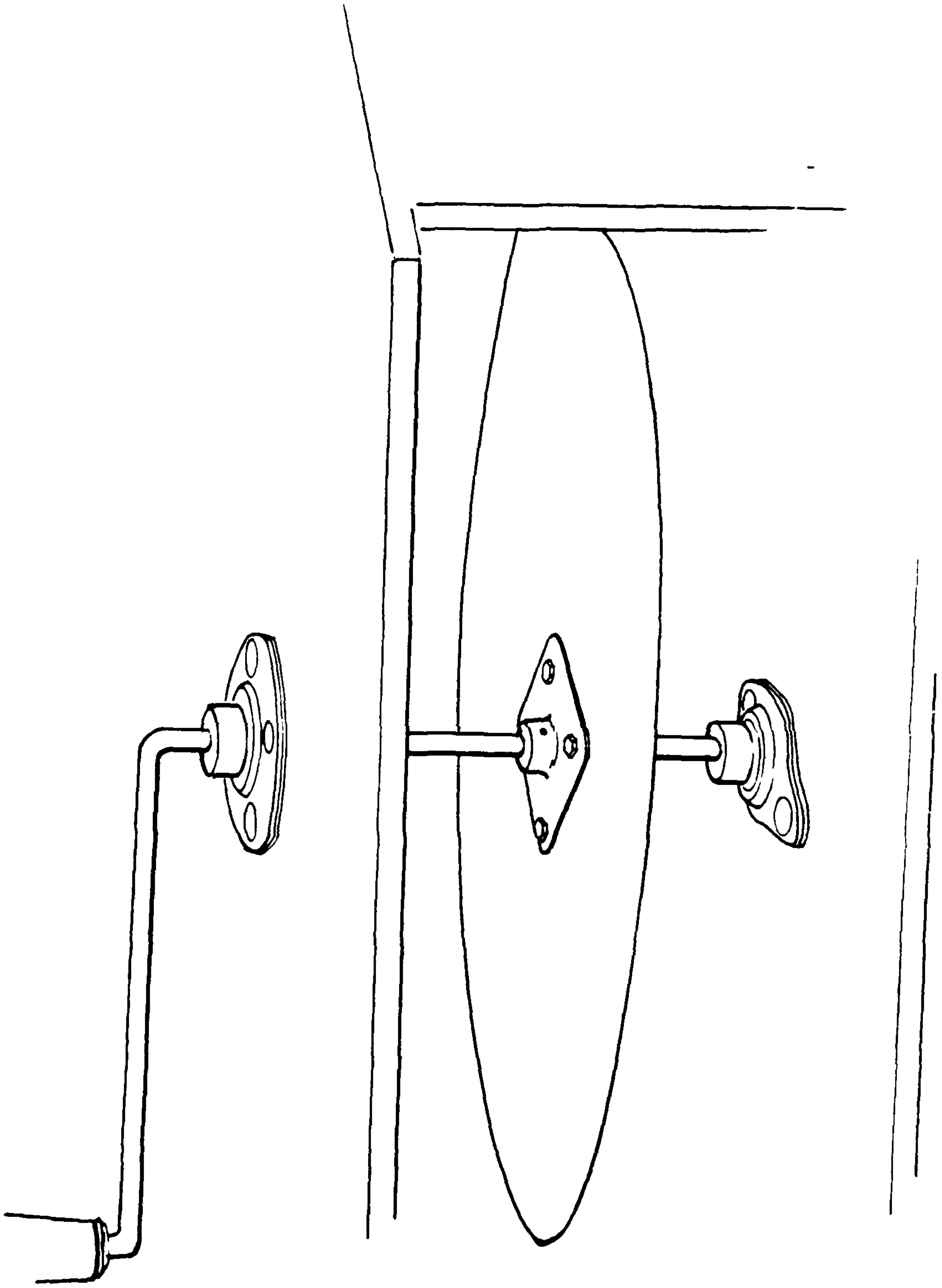

Figure 8.7. Attaching Disk to Crank Shaft.

I did one other thing to totally eliminate slippage about the crank shaft, but it was done as the very <u>last</u> assembly step for the entire apparatus. Once the optical scanner was built and installed in the crank box, and the relative positions of the disk and scanner were fairly well determined, I loosened the collar screws just enough to slip the disk around the shaft. I positioned the crank handle precisely at the midpoint of the box top and slipped the disk about the shaft, <u>holding the crank handle in place</u>, until the alignment hole was exactly between the infrared elements used to read it. When the disk and shaft were in this position, I retightened the collar screws, then totally detached the disk from the shaft. Where the upper collar screw had scratched the crank shaft I carefully drilled a dimple in the shaft, so the collar screw would seat in the dimple and prevent all slippage. The height of the disk inside the box could still be adjusted (slightly) via the machine bearings -- the shaft/disk assembly could be moved as one unit, up or down, through the bearings before the collar screws were tightened. The scanner assembly also retained its adjustability. However, all these capabilities for adjustment would not be enough to compensate for even a modest error in drilling the dimple in the crank shaft.

Optical Reader. The optical scanner was the most difficult item to build. I will begin with an explanation of the housing, then move to the wiring. Refer to Figure 8.8. The enclosure allowed for modest adjustment of the scanner array with respect to the disk. The scanner pier needed to be able to move left/right, up/down, and in/out.

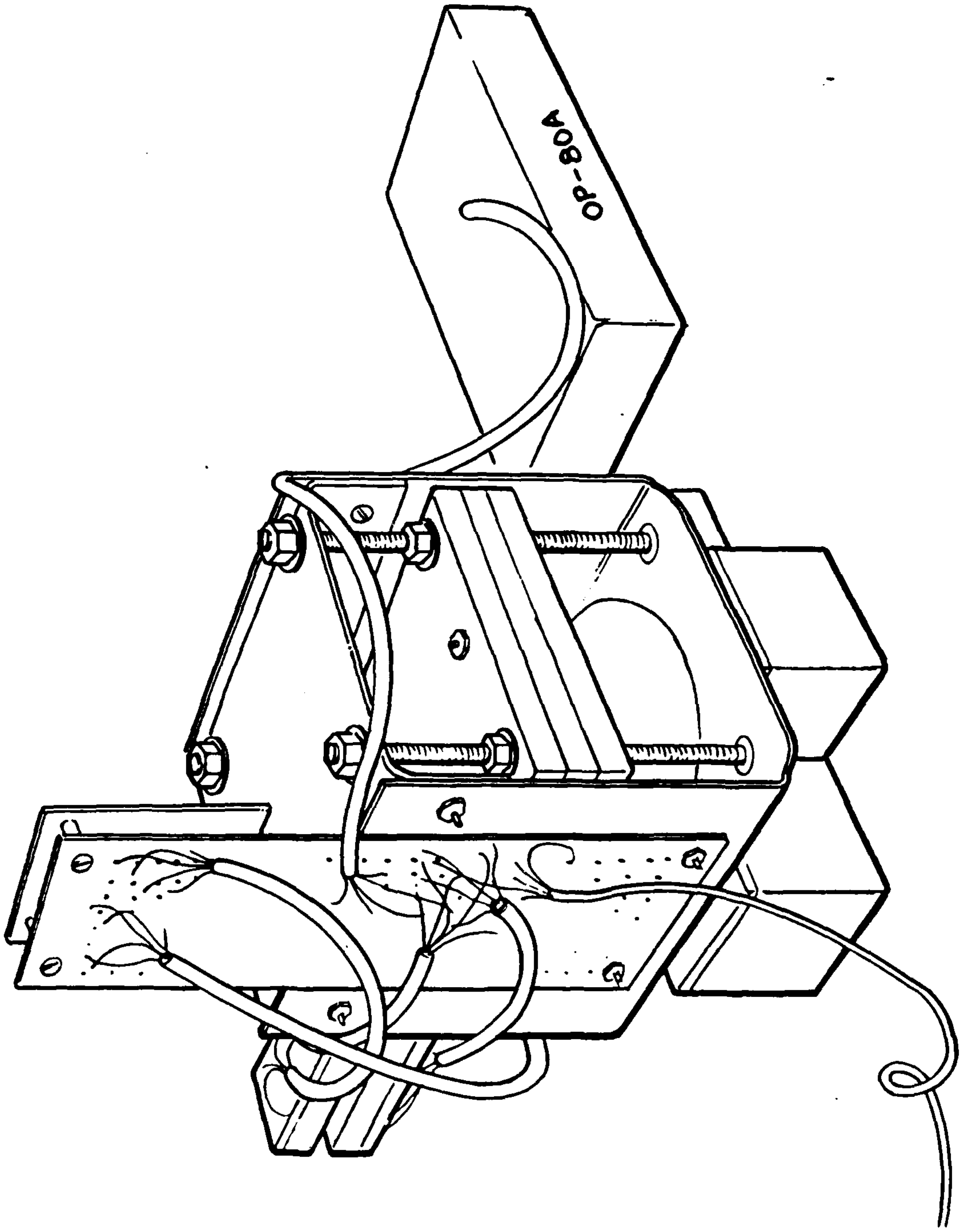

Figure 8.8. Enclosure for Optical Array.

Adjustability was limited to about 1/2" (plus or minus) for each of these dimensions. In addition, the entire housing was mounted in such a way (described below) that it could be rotated through approximately 45 degrees of arc.

The basic housing for the optical array was a metal box used to anchor 4" x 4" cedar posts as used for sun decks, etc. Within this box was a wooden "sandwich" assembly that actually held the infrared elements. The wooden assembly consisted of three parts: a 4" x 8" piece of 5/16" maple, a 4" x 8" piece of 1/4" pressed board, and a duplicate piece of maple. I chose maple because it was hard, strong, and did not warp. Unfortunately, it was hard to cut and drill, but other materials (such as plexiglas) proved totally unacceptable.

The wood pieces were clamped together while the assembly was being fashioned. Modifications to the 4" x 8" sandwich included: 1) trimming it to a width of 3 1/4"; 2) drilling four small holes to screw it together; 3) cutting a 3/4" wide, 4" long pier (which left a 3 1/4" x 3 1/4" platform); 4) drilling four 5/16" mounting holes for the 5/16" carriage bolts; 5) drilling eight 3/16" holes for the infrared emitters and detectors; 6) cutting the pressed board out of the pier portion of the sandwich, so the disk would be able to pass through the pier (the pressed board thus served as a spacer within the 3 1/4" x 3 1/4" platform portion of the wood sandwich). Step 5 required great precision and had to be carefully planned. The 3/16" holes had to be exactly 3/8" apart, and the hole farthest out on the pier had to be precisely aligned with the innermost hole on the disk if the rest of the holes were to line up correctly with the disk's holes. I did not drill

these until the entire optical scanner was built and tentatively mounted in the box (along with the crank/disk assembly), so rough aligning could be done before any holes were drilled on the pier. Refer to Figure 8.9 for a full-size template of the platform/pier sandwich.

Once the holes were drilled, the infrared emitters and infrared phototransistors were mounted in the pier. I chose infrared components because they were unaffected by ambient light and had very quick rise and fall times. The 3/16" holes in the pier provided a snug fit for these components, but I added a dab of glue to secure them better. The wooden sandwich was then ready to be mounted inside the metal post anchor box.

To prepare this box, I drilled four 5/8" holes in the top and bottom of it. These holes were purposely larger than the 5/16" carriage bolts that were to go through them, which allowed for some adjustability before tightening the bolts. This meant that the entire wooden sandwich could be moved within the post anchor when the carriage bolts were loosened, permitting some left/right and in/out correction.

The four 5/16" bolts were also used to adjust the height of the pier within the box via other sets of nuts and washers -- four each -- above and below the platform (see Figure 8.10). Thus, the pier could be exactly positioned so that the disk could pass smoothly through it.

The entire assembly was mounted on a block of wood that was 1 1/2" thick. This 4" x 4" square block was cut into a "+" shape so that the bolts that protruded from the post anchor box would not interfere with a level seating of the metal box onto the wood block (see Figures 8.8 and

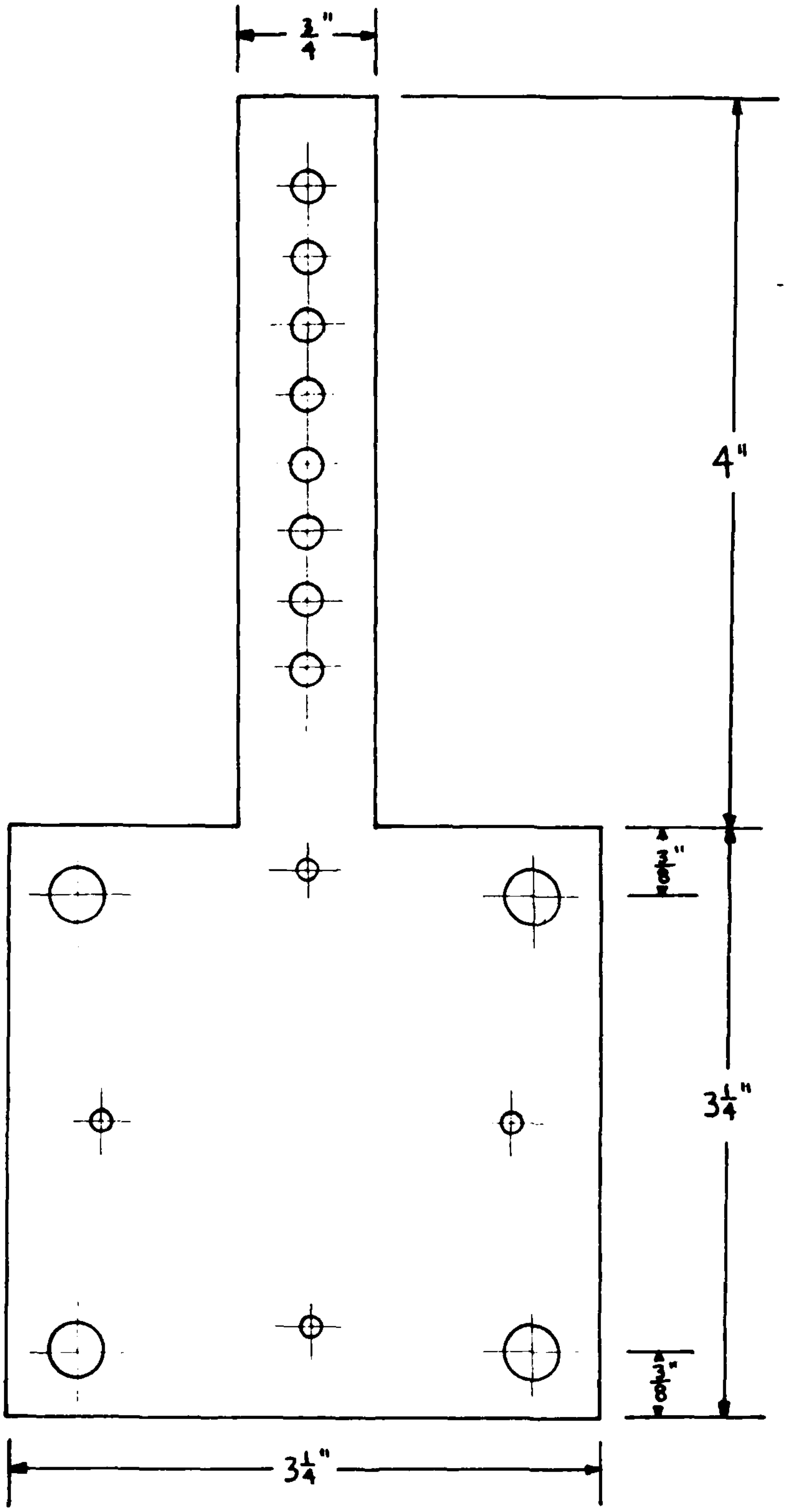

Figure 8.9. Template for Platform Pier (actual size).

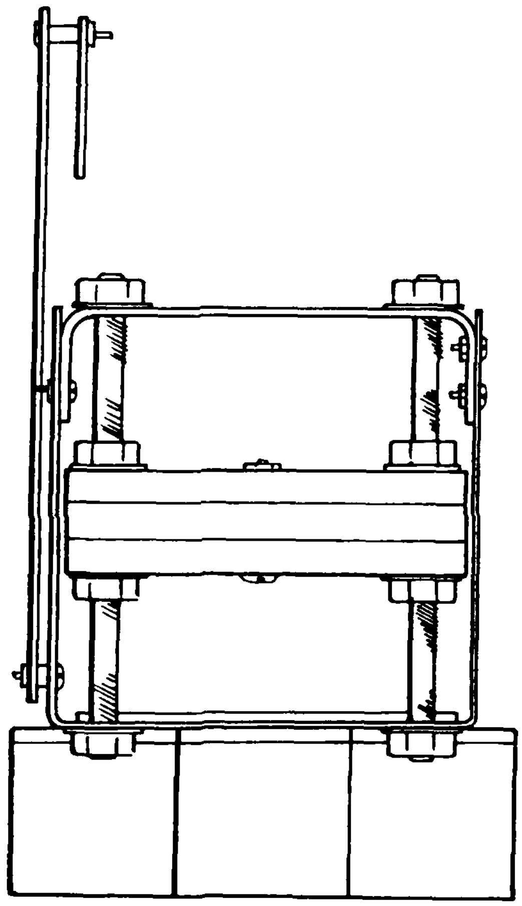

Figure 8.10. Rear View of Optical Scanner Housing (on Wood Block).

8.10). I also used a rubber pad, cut in the same shape as the block, on top of the block, which reduced any shock or vibration to the optical array. The wooden block and rubber pad had a 1/2" hole drilled through their centers, so a 1/2" carriage bolt could be used to attach the post anchor box to the rubber pad/wood block and this in turn to the floor of the crank box (the bolt was 2 1/2" long). The hole in the floor of the crank box was drilled after the tentative aligning of components within the crank box had been made final.

The wooden "+" block coupled to the metal post anchor may seem like a cumbersome arrangement, but it yielded important benefits. First, the optical assembly was elevated to approximately the halfway height within the crank box, which gave easy access to other components within the box (see Figure 8.5). Second, it let the scanner array rotate about the 1/2" bolt, an important aspect of adjustment for positioning the assembly with respect to the disk. Third, there was an asymmetrical washer that came with the post anchor kit, and using it with this assembly permitted even more tailored adjustments to be made (which proved to be a real boon!). I used this washer inside the post anchor box, inserting the 2 1/2"-long carriage bolt through it. Thus, the bolt went through the crank box floor, through the 1 1/2" wooden "+" block, through the rubber pad, through the asymmetrical washer, and then through a 1/2" nut. By loosening the nut, all mannner of moderate adjustments could be made just by manipulating the asymmetrical washer position within the post anchor.

The wiring for the optical scanner (and other wiring, notably, for the digital clocks and indicator lights) was located on an experimenter

board that was screwed to the side of the post anchor box (refer to Figures 8.8 and 8.10). This arrangement created a modular unit, so removal of the scanner for inspection or maintenance did not require many disconnections of wires. The wiring that was contained on this board is diagrammed in Figure 8.11.

Notice that the infrared phototransistors had their output fed into a "black box," the OP-80A unit (from Oliver Audio Engineering). This was a computer paper tape reader, modified for this particular application. Its own optical sensing element was removed and outputs from the phototransistors were wired directly into the empty socket. The diagram indicates what lines from the optical scanner went to which pins on the OP-80A. The only other modification to the paper tape reader was that the large multiple resistor was removed (refer to the documentation contained in the OP-80A assembly kit). This unit was used to condition the digital signals coming from the infrared phototransistors before the signals went to a COMTEC peripheral processor.

The paper tape reader was powered by a 5 VDC power supply. It was positioned in the crank box next to the optical scanner subsystem, held in place by a small corner brace on either side of it.

Two small 12-volt indicator lights were used to signal when the crank was positioned at the zero mark. The lights were mounted on the rear edge of the crank box lid, with one facing the subject and one facing the experimenter, so both persons could tell at a glance if the crank was aligned at the zero point (refer to Figure 8.5). These lights were wired into a circuit that sensed if the alignment hole on the disk was at the zero position, i.e., that the infrared set of elements

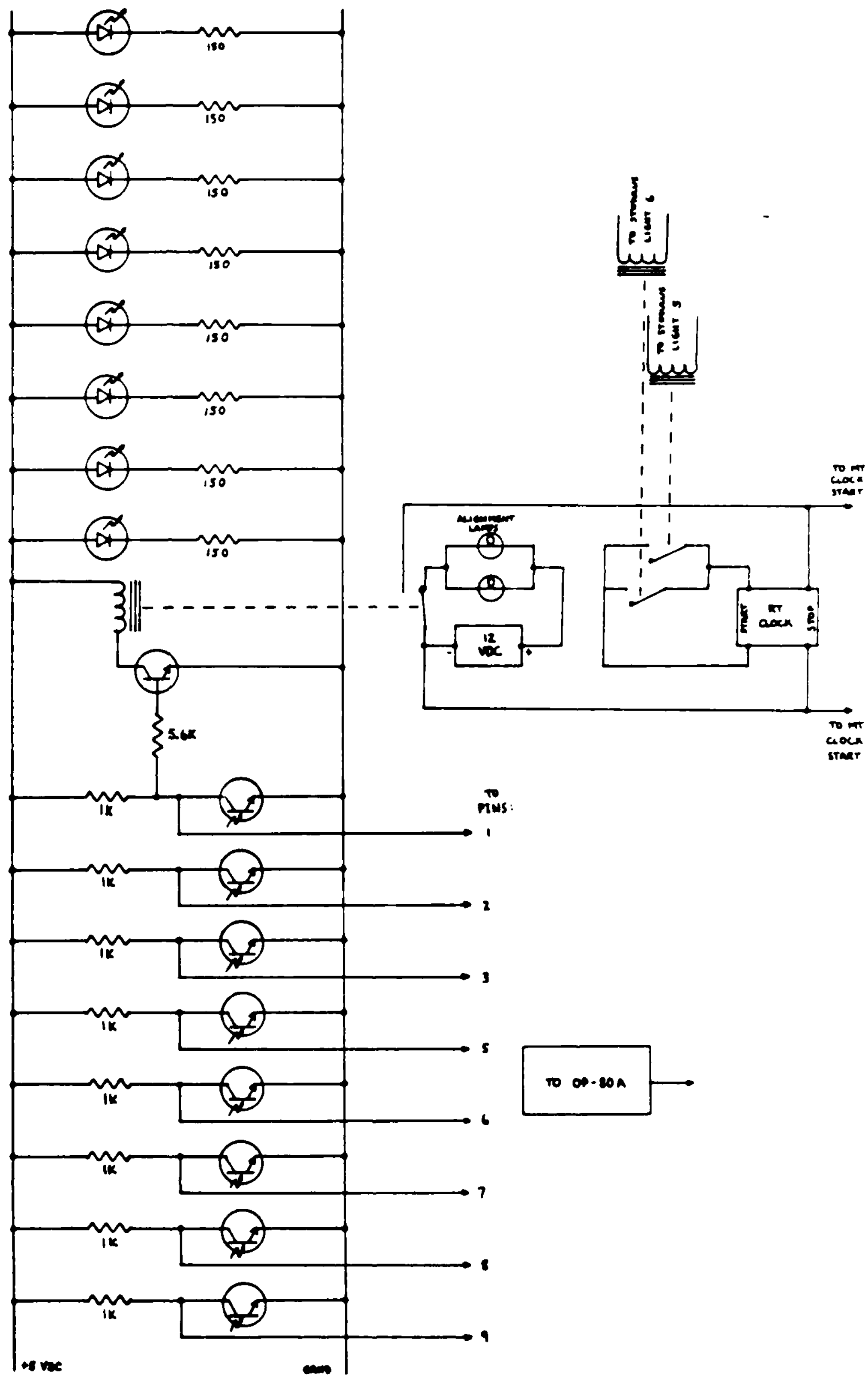

Figure 8.11. Wiring for the Optical Array and Indicator Lights.

farthest out on the pier could "see" through the alignment hole. [It should be noted here that the alignment hole was actually somewhat larger than the 3/16" holes drilled in the rest of the magnesium disk. This hole was 5/16" in diameter, which gave the crank a little play about the zero point -- about 1/2" at the crank handle.] When the zero point was reached, the infrared phototransistor pulsed, and this pulse was sensed by a separate circuit that then energized a relay, which in turn closed a circuit so that the lamps received 12 volts. Refer to Figure 8.11 to see how this circuit operated. As a side note, the reason the indicator lights used a separate circuit with its own power supply was because the 5-volt supply already powered many components: the OP-80A, the eight infrared emitters and eight phototransistors.

Before turning to the data gathering aspect of the optical scanning system, a brief summary of the subsystems built so far may be helpful. The metal crank was mounted via machine bearings to the top and bottom of a wooden box. Inside the box, attached to the shaft of the crank, was a magnesium disk with hole patterns drilled in it every four degrees. The hole patterns represented an eight-bit binary number that was read when the position passed through an eight-element infrared array. The array was mounted on an adjustable stand so it could be accurately aligned with respect to the disk. When the crank was positioned at the zero point, two indicator lights -- one for the subject and one for the experimenter -- illuminated. The output of the eight infrared phototransistors was fed through an OP-80A paper tape reader for signal conditioning, and then it was transferred to a COMTEC peripheral processor for data reduction.

Peripheral Processor. Unfortunately, these microcomputers were designed to accept analog signals and convert them to digital signals. They could not readily accept a "bare" digital signal, so modifications to the processor were made. In brief, this consisted of removing the analog-to digital conversion chip (U 30) on the mother board and feeding the digital inputs directly to the processor.

To do this, I had to make sure the correct inputs reached the processor. The output from the phototransistor farthest out on the pier was the least significant bit (LSB), while the output from the phototransistor at the other end of the pier was the most significant bit (MSB). Given this, the wires coming from the infrared array were labelled 1-8, with 1 as the least significant. These went to the OP-80A, as indicated by Figure 8.11. Note that pin 4 on the OP-80A was NOT used. Now refer to Figure 8.12, which shows the output of the OP-80A. These lines came from the I/O socket of the OP-80A, and though the pins were numbered differently, the hierarchy of bits (least to most significant) was still identifiable. These outputs were fed to certain pins in the U 30 socket in the peripheral processor (see Table 8.5). Additionally, pin 7 on the U 30 socket was utilized. This pin was vital, because it told the processor there was indeed a signal present and that the processor should read that signal. The input to pin 7 thus involved the following logic: "if one or more of the disk's holes is being read, there is a signal to process." Therefore, the processor was able to sense when there was at least one hole being "seen" by the phototransistors. The input to pin 7 in U 30 came from a circuit that mimicked the logic stated in the quotes above (see Figure 8.12). It

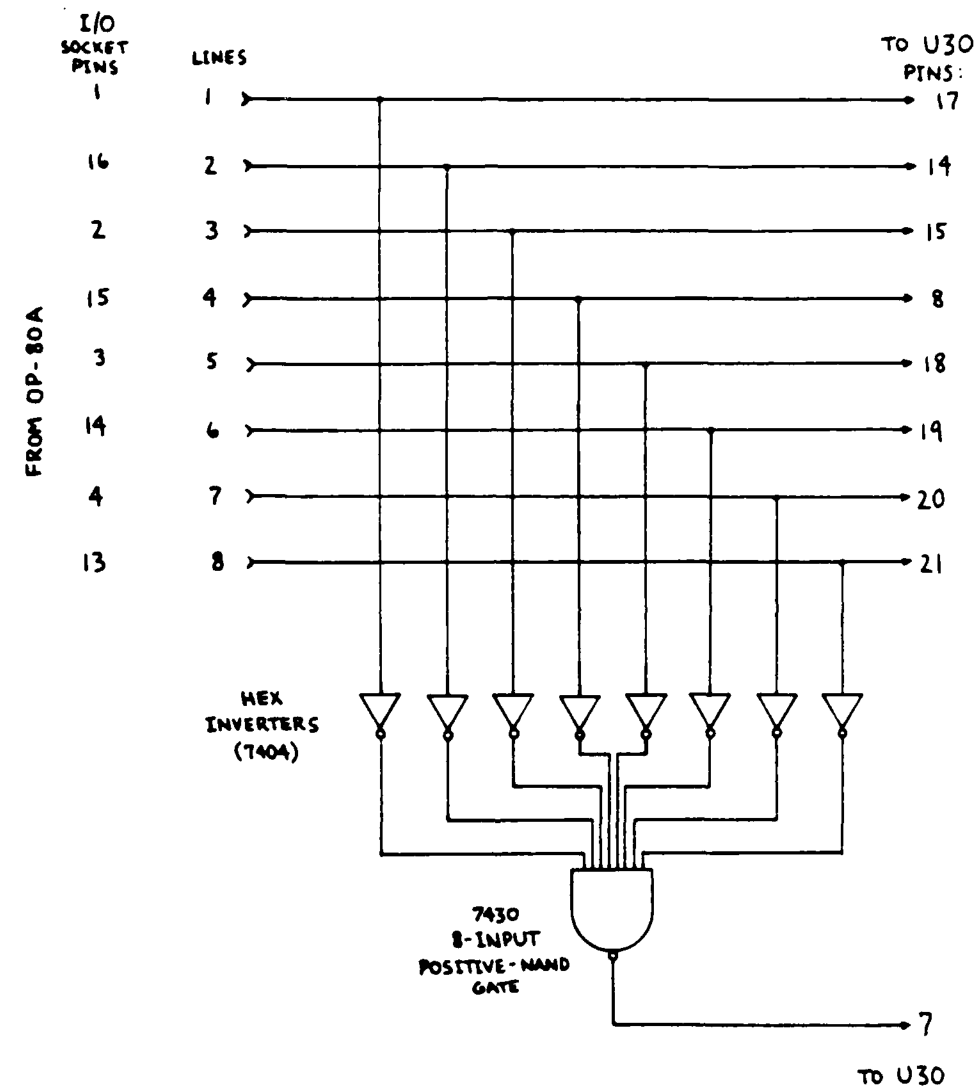

Figure 8.12. Circuit into U 30 Socket of COMTEC Processor.

basically took a parallel set of inputs from the OP-80A, inverted them, then used a positive-NAND gate to produce the desired output (which, as stated, was a signal to pin 7 indicating that at least one hole was being read). I used 7404 hex inverter chips and a 7430 positive NAND chip, wiring them onto an experimenter board located next to the peripheral processor. The chips received 5 VDC from auxiliary power connections on the peripheral processor mother board.

Table 8.5. Lines Corresponding to U 30 Pins.

Output from OP-80A	Line (LSB to MSB)	U 30 Pins
1	1	17
16	2	14
2	3	15
15	4	8
3	5	18
14	6	19
4	7	20
13	8	21

The software for the peripheral processor to read the disk is in Table 8.6. It is a very simple program, and I have included comments with it (again, these comments were not entered into the actual computer program). The peripheral processor read the input from the disk, then reported the crank position, in degrees. One important note is in order: as written, the program successfully reports position, but it is

Table 8.6. Program for Reading the Crank Position.

```
^B=%4000
NEW
5 GOTO 70
6 INPUT I                                          (READ CRANK POSITION)
10 IF I=Z GOTO 6                               (IF AT START, READ AGAIN)
15 IF I<>F E=1                                       (WHEN MOVE BEGINS
20 A=@%2C:B=@%2D:C=@%2E:D=@%2F                   READ THE CLOCK VALUES)
25 INPUT J
30 IF J<>G GOTO 25                           (WHEN FIRST TARGET REACHED
35 M=@%2C:N=@%2D:O=@%2E:P=@%2F                   READ NEXT CLOCK VALUES)
40 INPUT K
45 IF K<>H GOTO 40                          (WHEN SECOND TARGET REACHED
50 Q=@%2C:R=@%2D:S=@%2E:U=@%2F                   READ NEXT CLOCK VALUES)
55 INPUT L
60 IF L<>Z GOTO 55                           (WHEN THIRD TARGET REACHED
65 V=@%2C:W=@%2D:X=@%2E:Y=@%2F: GOTO 90  READ LAST CLOCK VALUES)
70 E=0:Z=1                                              (INITIALIZING)
72 "TRIAL TYPE?": INPUT T                             (READS KEYBOARD)
74 IF T>8 GOTO 125
75 IF T<5 GOTO 85
80 F=2:G=60:H=120: GOTO 6                     (SET TARGET POSITIONS
85 F=178:G=120:H=60: GOTO 6                   LEFT OR RIGHT MOVE *)
90 PRINT T,F,G,H
95 PRINT I,E
100 PRINT T,A,B,C,D                                 (90-115 ARE JUST
105 PRINT J,M,N,O,P                                  SCREEN OUTPUTS
110 PRINT K,Q,R,S,U                                 AS CHECKS ON THE
115 PRINT L,V,W,X,Y                                         PROGRAM)
120 PRINT:PRINT:PRINT: GOTO 70
125 "TO RECOVER, HIT ANY KEY. 9 STOPS PROGRAM"
130 INPUT T: IF T<>9 GOTO 70
135 "ALL DONE"
```

* NOTE: THIS PROGRAM LOOKS FOR ONLY THREE TARGET VALUES ON THE METAL DISK, BUT THIS NUMBER MAY BE INCREASED. LINE 75 TESTS IF IT IS TO BE A LEFT MOVE (T < 5) OR RIGHT MOVE (T > 4) AND ASSIGNS THE PROPER TARGET VALUES FOR THE COMPUTER TO LOOK FOR (F,G, AND H IN EITHER LINE 80 OR 85). WHAT THE COMPUTER THEN DOES IS READ EVERY POSITION TO SEE IF THE TARGET HAS BEEN REACHED. WHEN IT HAS, THE COMPUTER STORES THE CLOCK VALUES (TO THE NEAREST 1/100 SEC), THEN SEARCHES FOR THE NEXT TARGET. FOR THIS PARTICULAR PROGRAM, THE LAST TARGET IS IN LINE 60. THIS TARGET IS Z, OR THE START POSITION, SO THE END OF THE MOVE IS FINISHING THE CIRCLE. THE OTHER COMPARISONS ARE MADE IN LINE 15 (FOR INITIAL MOVEMENT), LINE 30 (FIRST TARGET), AND LINE 45 (SECOND TARGET), WHERE THE TARGETS F,G, AND H HAVE BEEN ASSIGNED IN LINE 80 OR 85, BASED ON A LEFT OR RIGHT MOVE.

not entirely adequate for all types of moves, particularly high-speed moves. To increase the processor's ability to read positions very quickly, an assembly language subroutine needs to be written.

Crank Stand. This is not described in detail since a variety of stands may be used. The one built for this experiment had a rectangular base made out of 2" x 8" wood. The floor for this rectangular base extended for 4' in front of the base, so the subject actually stood on a (carpeted) wooden platform that was integral to the base. This decreased the amount of sliding that the crank stand did across the floor when the crank was turned forcibly. I did two other things to totally eliminate sliding and make the stand a stable one for the crank. I put rubber pads on the bottom of the platform and put brick weights in the rectangular base.

Four 2" x 4" pieces of wood, 37" long, extended vertically from the rectangular base, one from each inside corner. From 24" to 36" above the floor, I drilled 3/8" holes at 1" intervals on each post. This was so a platform could be raised or lowered inside the area bounded by the posts, the crank box sitting on this platform. The platform was made of a 2" x 4" wood frame and a plywood top. It was bolted between the four posts of the crank stand with 3/8" carriage bolts that were 3 1/2" long. The crank box had two holes in its floor for 1/4" carriage bolts. These corresponded to holes drilled in the top of the platform. Thus, the crank box could be bolted to the platform, which was in itself securely bolted to the four posts. The sturdy wood used and the large bolts employed for the post-to-platform connection made it a rigid stand. The

four 3/8" carriage bolts and the two 1/4" bolts were all secured with wing nuts. This permitted rapid removal of the crank box from the platform, and of the platform from the posts of the stand. This was a considerable aid, because I had to adjust the height of the crank for practically every session (100 of them!). The crank box could be removed easily and set aside, then the platform height adjusted, and finally the crank box replaced -- all within seven minutes.

8.2 Supplemental Analyses

1. Demographics on Subjects. There were certain descriptive statistics collected on subjects that did not warrant inclusion in the main text. They are of some value in describing the sample, however, especially for replication purposes. Below is a listing of the more relevant data:

   a. Average Age: 20.9 yrs

   b. Average Height: 70.4"

   c. Range of Height: 60" - 76"

   d. Range of maximum arm strength (2 min): 1.0 kg - 1.4 kg

   e. Range of minimum work (20 min @ 20% max): 214 - 300 watts

   f. Range of maximum work (20 min @ 80% max): 856 - 1200 watts

2. Rating of Perceived Exertion. As stated in the Results section, there was a high positive correlation ($r = .92$) between the actual exercise level and subjects' local RPEs. Hence, the coefficient of determination was .8436, which meant that a great deal of the variance in RPE was actually due to the exercise. The regression equation was

$$Y = 13.125(X) + 7.34$$

The slope tested significantly different from zero ($t < .0001$) and was such that for each increase in exercise to the next level, there was an increase in RPE of about 2.5 units.

3. _Post hoc_ Test on MT Data. Though a trend test was done on the MT data, this did not tell which of the four means differed from each other. The Tukey Wholly Significant Difference (WSD) technique found

each level differed from every other ($p < .05$). But even though statistical significance was achieved, the MT means for the first three exertion levels could hardly imply practical significance (405 msec, 409 msec, and 413 msec for the 20%, 40%, and 60% exertion levels, respectively). The 80% exertion level had a mean of 444 msec, a considerable change from the other three and one that does have practical relevance. The slowdown represents a 10% decrease in speed for the speeded, ballistic task of this experiment.

4. Directional Effects. There was actually a fourth independent variable in the experiment, that of the direction of movement. Moves could begin and end either to the left or to the right. There was an equal number of right and left moves for each trial type to balance this factor across other treatments. The ANOVAs reported in the main text simply collapsed across this factor since it had no relevance to the other independent variables. The ANOVAs for ART and MT did reveal effects from direction, however, and they are discussed here.

Anticipatory Response Time. There was a main effect of direction on ART ($F = 37.35$, $p < .0001$). Moves that began to the right had a mean response time of only +7 msec while moves that began to the left had a mean response time of +29 msec. But why should the direction of movement affect a central processing (which response time reflects)? The simple answer is that it should not and probably does not.

The difference in scores is most likely an artifact of the characteristics of the required move. Christina, Fischman, Vercruyssen, & Anson (1982) studied various RT artifacts due to the type of move

demanded in the skill. Among other things, they found discrepancies in how moves were initiated, namely, muscular activation was not symmetric for moves beginning to the left vs. right. They found that a ballistic move to the right actually began with the elbow, and the forearm and hand followed. But a move to the left employed the entire arm segment, from shoulder to hand, as one piece. It is obvious that a move beginning to the left involves larger mass to overcome and can therefore be expected to be slower in its start due to greater inertia. Christina et al. found a 39 msec difference in RT due to this effect. Indeed, this is more than enough to account for the 22 msec difference reported here. It can be safely concluded that there are no central information processing effects attributable to merely starting a move in a particular direction.

Movement Time. There was a strong main effect for direction ($F = 55.39$, $p < .0001$). This confirmed what subjects reported in the exit interview, i.e., a move starting and ending to the left was the more difficult of the two. This was because all subjects were right-handed, and a move to the left involved moving across the body twice. The average time for a left move was 441 msec and for a right move, 395 msec. As stated above, these effects were averaged across all treatments equally.

5. Error Data. From the Jonckheere Test for Ordered Alternatives, it may not be intuitively clear that a main effect existed for ERR. This section merely reports the results of other, more direct nonpara-

metric tests for main effects. The Bradley Addition Test (Bradley, 1968) was performed on the Continuity variable and the result was significant ($H' = 5.49$, $p = .02$). Switched trials produced a higher error rate than normal trials did. A similar test was done for Speed and the result was also significant ($H' = 6.5$, $p = .01$). There was a higher error rate on fast trials than on slow ones.

6. Sequential Effects. At the outset it was thought that a switched trial might influence performance on the trial that followed it. For example, a subject could still be bothered by the switched trial and the timing of the subsequent trial could be disrupted. Or a subject could "play the odds" and, knowing a switched trial had just occurred, assume that the next trial would certainly be a normal one.

A 3 X 4 ANOVA tested these ideas. The first factor was trial Position, and the three levels were: 1) normal trial; 2) switched trial; and 3) normal trial that immediately followed a switched trial. The second factor was Local Exertion. As expected, the result was significant for Position using ART as the dependent variable ($F = 34.41$, $p < .0001$) and MT as the dependent variable ($F = 44.41$, $p < .0001$). A Tukey WSD test found each mean to be different from every other ($p < .05$), but an inspection of the means revealed little practical significance. Most of the difference in ART and MT scores centered on the mean of the switched trials. Performance on trials following a switched trial was really quite similar to trials preceding switched trials, despite statistical significance (e.g., ART-1 = 12.5 msec vs. ART-3 = 13.4 msec; MT-1 = 414.2 msec vs. MT-3 = 420.9 msec).

7. F-ratios. Certain F-ratios, most notably in the ANOVA using CE scores, were well below the theoretical minimum of 1.00. This was attributable to a bimodal distribution about zero (perfect coincident timing), with early and late responses forming either half of the distribution. Additionally, note that the F-ratios which were less than 1.00 occurred only for the A factor (local exertion). This factor was known to produce high variation between and within subjects. This fact could account for the inflation of error terms, which in turn produced the low F-ratios. Be that as it may, the interpretation of the ANOVA results using CE (bias) scores is essentially unaffected, since *a priori* hypotheses posited no effects on timing from local exertion.

END

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